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THE UNIVERSITY OF ALBERTA

PHYSIOLOGICAL RESPONSES TO VARIOUS AMBIENT TEMPERATURES ($4^{\circ}C$ TO $40^{\circ}C$) DURING EXERCISE

by

© GASTON GODIN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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THE UNIVERSITY OF ALBERTA

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ABSTRACT

The effects of exercise plus environmental temperatures was studied using six human subjects, 24 to 34 years of age. Subjects exercised for twenty minutes at seventy-five per cent of their individual $\dot{M}VO_2$ under three different environmental temperatures on three different occasions. The temperatures used were 4, 21, and 40 degrees C. Blood glucose, plasma total fatty acid, plasma lactic acid, $\dot{V}O_2$, $\dot{V}e$, and H.R. were measured at rest, and after two, seven, and twenty minutes of bicycle ergometer exercise. Exercise had no significant effects on blood glucose concentration and on total plasma fatty acid level. There was a marked effect ($p < 0.01$) on plasma lactate level, $\dot{V}O_2$, $\dot{V}e$, and H.R. Environmental temperature during exercise had no significant effects on blood glucose concentration, total plasma fatty acid level, plasma lactate level, $\dot{V}O_2$ and $\dot{V}e$. However, when $\dot{V}O_2$ was expressed per kilogram of body weight there was a significant ($p < 0.1$) difference between cold results and the two other temperatures. Oxygen consumption per kilogram was higher under cold environmental temperature. Heart rate was also higher ($p < 0.05$) during exercise at 40 degrees C.

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CHAPTER I

INTRODUCTION

The energy expended during increased metabolic activity of tissues may be derived from carbohydrates, lipids or proteins, as well as from the intermediary products of their breakdown (61). The choice of a certain energy substrate is determined not only by the actual content of a given nutrient in the organism, but also by the conditions and possibilities of their mobilization and utilization (68).

It is well known that both plasma glucose and free fatty acid (FFA) play an important role in energy metabolism (8, 18, 21, 22, 25, 38, 37, 44, 53, 54). These two major energy sources are mobilized from glycogen and fat depots. Glucose is stored in limited quantities as glycogen in the liver and muscles (31, 43, 47). Fat, in the form of triglycerides, is stored primarily in adipose tissues, in the splanchnic area and, to some extent, in and around muscles (19, 43, 47). Glucose and FFA are mobilized from these energy depots via the circulatory system (44).

The mobilization of various energy sources may be affected by different endogenous and exogenous factors. Exercise and environmental temperature are two exogenous causes which may alter, quantitatively and/or qualitatively, this mobilization. These two exogenous causes are important because they represent two metabolic stresses under which men have to perform (1, 5, 9, 13, 17, 24, 29,

39, 40, 42, 55, 56, 57, 78).

Statement of the Problem

The problem was to find how the body reacts during exercise, under various environmental temperatures, by measuring the alterations of the following physiological parameters:

1. the blood glucose concentration
2. the percentage of total saturated fatty acid versus total unsaturated fatty acid in plasma
3. the plasma lactic acid concentration
4. the oxygen consumption ($\dot{V}O_2$)
5. the minute ventilation ($\dot{V}e$)
6. the heart rate (H.R.)

Justification of the Study

Our country is one where we see four seasons in succession. In a given year the environmental temperature fluctuation can be from 40 degrees C below zero in winter to 40 degrees C above zero in summer time. A jogger who enjoys exercise outside, exposes his body to this environmental temperature range. It is important to know how the body reacts to combined exercise and temperature stresses.

Delimitations of the Study

The design of this study was delimited to:

1. six volunteers, physical education students, at the University of Alberta.
2. an exercise for twenty minutes at seventy-five per cent maximal oxygen consumption ($\dot{M}VO_2$) on an ergometer bicycle.
3. the following temperatures and relative humidities
   a) 4 degrees C and 82.5% relative humidity in the cold room.
   b) 21 degrees C and 24.2% relative humidity in the laboratory room.
   c) 40 degrees C and 19.9% relative humidity in the sauna room.

Definition of Terms

In order to avoid misunderstanding, the following terms were defined:

Anova: The statistical technique of analysis of variance.

Acclimatization: Pertaining to certain physiological adjustments brought about through continued exposure to a different climate, e.g., changes in altitude and temperature.

Acid: A chemical compound that gives up hydrogen ions (H^+) in solution.

Aerobic: In the presence of oxygen.

Ambient temperature: Pertaining to the surrounding environment. The degree of sensible heat or cold.

Anaerobic: In the absence of oxygen.

Barometric pressure (P_B): The force per unit area exerted by the earth's atmosphere. At sea level, it is 760 millimeters of mercury (mm Hg).

Carbohydrate: Any of a group of chemical compounds, including sugars, starches, and cellulose, containing carbon, hydrogen, and oxygen only. One of the basic foodstuffs.

Douglas bag: A rubber-lined, canvas bag used for collection of expired gas.

Dry bulb thermometer: A common thermometer used to record temperature of the air.

Ergometer: An apparatus or device, such as a treadmill or stationary bicycle, used for measuring the physiological effects of exercise.

Fat: A compound containing glycerol and fatty acids. One of the basic foodstuffs.

Fatty acid: Fatty acids are the building blocks of several classes of lipids. The sources of fatty acids are intracellular (tissue stores) as well as extracellular (supplied via the vascular system). The fatty acids are stored in the cell and must be mobilized and transported across the mitochondrial membrane. Once inside the mitochondrial membrane, the fatty acid is available to the

enzymes of fatty acid oxidation, which are located on the mitochondrial membranes.

Glycolysis: The incomplete chemical breakdown of glycogen. In aerobic glycolysis, the end product is pyruvic acid; in anaerobic glycolysis, the end product is lactic acid.

Lactic acid: In the absence of oxygen glycolysis can continue and the end product is lactic acid rather than pyruvic acid. This system of nonoxidative glucose metabolism is referred to as the anaerobic phase of glycolysis.

Lipolysis: The process of mobilization of fatty acids from adipose tissues which increase the concentration of plasma fatty acid and glycerol.

Maximum oxygen consumption ($\dot{M}VO_2$): The maximum oxygen consumption is the maximal volume of oxygen (at $0^{\circ}C$, 760 mm Hg, dry) extracted from the inspired air, usually expressed in liters per minute ($\dot{M}VO_2$).

Minute ventilation ($\dot{V}e$): The volume of air (at $0^{\circ}C$, 760 mm Hg, dry) expired during one minute, usually expressed in liters per minute.

Plasma free fatty acid (FFA): A quantity of fatty acids is always present in the blood combined with the albumin of the plasma proteins. The fatty acid bound with proteins in this manner is called free fatty acid (FFA) or nonesterified fatty acid (NEFA).

Plasma glucose: A monosaccharide of importance found in the blood. The most common form of carbohydrate substrate used by the body.

Relative humidity: Ratio of water vapor in the atmosphere to the amount of water vapor required to saturate the atmosphere at the same temperature.

Saturated fatty acid: A fatty acid which does not have a double bond.

Unsaturated fatty acid: When a fatty acid molecule contains a double bond, it is said to be unsaturated.

Wet bulb thermometer: An ordinary thermometer with a wetted wick wrapped around the bulb. The wet bulb's temperature is related to the amount of moisture in the air. When the wet bulb and dry bulb temperatures are equal, the air is completely saturated with water and the relative humidity is equal to 100 per cent.

CHAPTER II

REVIEW OF RELATED LITERATURE

The Effects of Exercise

1. Glucose

Klachko et al. (45) studied the effect of low intensity exercise on blood glucose level. Twenty-eight human subjects, aged 18 to 48 years, exercised on a treadmill, walking half-mile walks at 4 mph, one on a 2.5° slope and two on a 5° slope. At 2.5° slope the pre-exercise blood glucose level was 82.1 mg/100 ml and after the walk the group showed a modest decrease of 5.3 mg/100 ml in glucose concentration. On the 5° slope the decrement in glucose doubled with a mean decline of 11.7 mg/100 ml.

Pruett (58) in an experiment where nine healthy young men, 22 to 33 years of age, exercised at three different intensity levels, added further information on blood glucose concentration after exercise. Under a standard diet, at twenty per cent of their $\dot{M}VO_2$, there was a statistically significant ($p < 0.02$) fall in the blood glucose concentration from the pre-exercise level. The reduction was from 96.2 to 90.6 mg/100 ml. At an intensity of fifty per cent of the subjects' $\dot{M}VO_2$ there was a statistically significant ($p < 0.001$) fall in blood glucose levels (96.2 to 62 mg/100 ml). A similar average fall in blood glucose level also occurred when the subjects worked at a load representing seventy per cent of their $\dot{M}VO_2$ (96.2 to 62.5 mg/100 ml).

However, Hermansen et al. (26) found the glucose concentration stable at work loads averaging seventy-seven per cent of the subjects' individual maximal aerobic power. Two groups (trained and untrained) of ten healthy male subjects worked to complete exhaustion on a bicycle ergometer. Before work, the mean blood glucose concentration was 93 mg/100 ml in the untrained and 87 mg/100 ml of blood in the trained group. At the end of twenty minutes of exercise it dropped to 83 and 82 mg/100 ml respectively, and remained at almost constant level until exhaustion.

Research by the same author showed that exercise near the $\dot{M}VO_2$ increased the mean blood glucose concentration (27). Five healthy subjects ran on a treadmill at their greatest possible speed for five one minute bouts. Each exercise period was followed by a four minute rest period. Hermansen et al. (27) found that the mean blood glucose increased from 90 mg/100 ml at rest to 170 mg/100 ml immediately following the fifth work bout.

In the light of the preceding reports, we can presume that blood glucose concentration level depends on the severity of the work load and the major food fuel is glucose when the predominant pathway is anaerobic.

2. Free Fatty Acid (FFA)

i) Level

Rodahl et al. (62) found that the plasma concentration of FFA was stable. Eight men, 19 to 38 years of age, participated in

studies on the effect of exercise of different intensity and duration on plasma FFA. At the end of intermittent work for thirty minutes or, moderate work of 900 kpm on the bicycle ergometer for sixty minutes, plasma concentration of FFA was essentially the same at the end of the work period as the pre-exercise value.

In a series which included work loads up to seventy per cent of $\dot{M}VO_2$, Pruett (59) found that plasma FFA levels increased progressively during exercise at all work loads. The average pre-exercise values and the values at the end of exercise for plasma FFA were 0.576 and 2.025 mEq/L at fifty per cent $\dot{M}VO_2$ and, 0.465 and 1.515 mEq/L at seventy per cent $\dot{M}VO_2$.

The results of Hurter et al. (32), Vihko et al. (71, 72), are in agreement with Pruett's finding (59). Hurter et al. (32) found that the concentration of FFA rose in fourteen athletes after a forty-two kilometer race over flat ground in a mean time of two hours fifty minutes. There was a significant ($p < 0.001$) difference between the pre-exercise and post-exercise values. At rest the FFA concentration was 0.60 mEq/L and after the race it was 1.38 mEq/L.

FFA in plasma was measured at rest and after aerobic ergometer work by Vihko et al. (71) on sixteen young males, 17 to 35 years of age. The exercise session consisted of three separate phases. Phase I was six minutes at 1,200 kpm/min, phase II consisted of twenty minutes at 900 kpm/min and phase III was nineteen and a half minutes at 900 kpm/min followed by half a minute at 1,500 kpm/min. There was a rest period of thirty-four minutes and thirty minutes after phases I and II respectively. The total plasma FFA concentration was 565 uEq/L

before work and increased significantly ($p < 0.001$) to 802 uEq/L after work.

Using the same exercise protocol, Vihko et al. (72) found a significant increase in total FFA after exercise. For untrained subjects the rest value of 587 uEq/L increased to 886 uEq/L after exercise ($p < 0.001$). Mean trained subjects'total plasma FFA concentration was 611 and 828 uEq/L respectively before and after exercise ($p < 0.02$).

There is no longer any doubt that the oxidation of fat plays a vital role in the provision of energy for sustained muscular activity. The plasma FFA level, for instance, may increase (32, 59, 71, 72) during work, or it may remain unaltered (62), depending on the intensity and duration of the exercise.

ii) Composition

In a study where fourteen athletes ran forty-two kilometers, Hurter et al. (32) found no significant changes in plasma concentrations of cholesterol, phospholipid, or triglyceride immediately after exercise. However, significant changes were found after exercise in the fatty acid composition of each of the four lipid fractions. In the FFA, there was a reduction in stearate and an increase in linoleate. The percentage distribution of stearic was 15.65 at rest and 12.25 after exercise ($p < 0.02$). Linoleic accounted for 7.96 per cent at rest and increased to 9.35 per cent after exercise ($p < 0.05$). The triglyceride, cholesterol ester, and phospholipid fractions each showed a decrease in one of the unsaturated acids (oleate or linoleate),

with a corresponding rise in a saturated acid (palmitate or stearate).

In the study of Vihko et al. (71) the changes in the concentration of individual plasma FFA were significant ($p < 0.001$) in every acid studied. The concentration of individual plasma saturated FFA increased from rest to the end of exercise. Palmitic and stearic acids increased respectively from 226 and 70 uEq/L to 311 and 82 uEq/L after work. The same pattern occurred for the individual plasma unsaturated FFA. Palmitoleic, oleic and linoleic acids increased respectively from 29, 139, and 102 uEq/L to 55, 231, and 126 uEq/L after exercise.

However, the percentages of individual fatty acid of the FFA and the per cent of their contribution to the total FFA were not the same after as before work. The per cent contribution of palmitoleic and oleic acids increased ($p < 0.001$) while it decreased significantly ($p < 0.005$) for the other acids.

Vihko et al. (72) using the same exercise protocol as Vihko et al. (71), found similar results using trained and untrained subjects. For untrained subjects, there was a significant increase in all individual fatty acids studied. The values of 221 and 64 uEq/L at rest increased to 333 and 82 uEq/L respectively for palmitic and stearic acids after exercise. For unsaturated acids, the values of 26, 132 and 103 uEq/L at rest rose to 61, 264 and 144 uEq/L after work respectively for palmitoleic, oleic and linoleic acids.

In trained subjects there was no significant difference in stearic and linoleic acids. However, for the untrained subjects, there was a significant increase in palmitic, palmitoleic and oleic acids.

The concentration of 238, 32 and 164 uEq/L at rest rose to 326, 61 and 230 uEq/L after exercise for the three individual plasma fatty acids respectively.

It seems that the relative proportions of the individual fatty acids within FFA are altered during exercise. Each individual fatty acid concentration increased after exercise but the per cent contribution of each does not follow the same pattern. Unsaturated acids increased in proportion whereas saturated acids decreased.

3. Lactic Acid

In their study on the effect of increasing work load on blood lactic acid concentration, Wells et al. (74) used six human male subjects working on a treadmill. The speed of the treadmill was constant at 3.5 mph and the work load was increased in minute intervals by elevating the treadmill angle. Starting from a horizontal position, the angle was increased by 2% at the end of the first minute and thereafter the angle was increased 1%. The exercise bout was terminated two minutes after the subjects had achieved a heart rate of 180 beats/min. Blood samples were collected during exercise at pulse rates of 120, 140, 160 and 180 beats/min and during the two minutes each following the latter.

There were three distinctly different increments of lactic acid accumulation in the blood during gradually increased work. During light exercise, in the initial eight minutes of work, pulse rate increased to 120 beats/min and the lactic acid did not exceed the

normal range. The values of 16.5 and 19 mg/100 ml were obtained at rest and at the eighth minute of exercise, respectively. During moderate work, with pulse rate between 120 and 160 beats/min, lactic acid in the blood accumulated in a linear relationship with the increase of work intensity up to a value of 38 mg/100 ml. During severe work, with a pulse rate above 160 beats/min, lactic acid increased to 100 mg/100 ml or more.

The results of Pruett (59) are in agreement with those of Wells et al. (74). At fifty per cent $\dot{M}VO_2$ blood lactate increased from 8.1 to 14.5 mg/100 ml for pre-exercise and end of work values, respectively. At seventy per cent $\dot{M}VO_2$ the results were 10.6 mg/100 ml at rest and 23.6 mg/100 ml at the end of work.

It appears evident that lactic acid concentration in the blood increased as the work load increased.

4. Oxygen consumption ($\dot{V}O_2$)

It is obvious that oxygen consumption increases during exercise (3, 6, 11, 55, 74, 76). As previously mentioned, Wells et al. (74) tested their subjects on a treadmill at a constant speed increasing the work load by elevating the treadmill angle. Oxygen uptake was 0.265 L/min at rest and increased to 3.003 L/min at the end of the work session. In that particular study the oxygen consumption rose to about twelve times the resting value.

Åstrand et al. (3) studied $\dot{V}O_2$ during the first minutes of heavy exercise. Muscular work was performed on a Krogh bicycle

ergometer by five subjects. The results show an increase in $\dot{V}O_2$ as the heavy work proceeds and the rate of the increase in $\dot{V}O_2$ varies with the work load.

5. Minute Ventilation ($\dot{V}e$)

It is also well known that $\dot{V}e$ increases with increasing work load during exercise. In their experimental protocol, Wells et al. (74) tested subjects over a wide range of work loads. The work load was assessed by measuring the heart rate. Exercise was done from a heart rate of less than 120 and over 180 beats/min. The average experimental $\dot{V}e$ was 6.7 L/min at rest and progressively increased to 93.1 L/min with increasing work load from light to heavy work.

Asmussen et al. (2) and Åstrand et al. (3) found results which are in agreement with the above conclusions.

6. Heart Rate (H.R.)

It was demonstrated by Wells et al. (74) that H.R. increased from 66 beats/min at rest to 191 beats/min at the end of exercise periods where work intensity was increased from rest to 1,500 m-kg/min. This and other evidence clearly shows that as work load increases, so does heart rate.

The Effects of Temperature

1. Glucose

Blood glucose concentration in rats appears to increase during cold exposure whereas exposure to a warm environment seems to result in no significant effects.

Gilgen et al. (20) exposed twelve Sprague-Dawley rats for three hours at 4 degrees C. There was a sixty-five per cent increase in plasma levels of glucose.

Himms-Hagen (28) studied the effect of either cold or warm exposure on blood glucose concentration of warm-acclimated and cold-acclimated rats. There were two groups of white rats: one group made up of forty-three rats was kept at room temperature (19 to 24 degrees C), and the other group made up of twenty-seven rats was kept in the cold room (2 to 4 degrees C) for thirty-three to seventy-four days. Then, exposure to cold for one hour and a half to three hours slightly increased ($p < 0.01$) blood glucose concentration in the warm-acclimated rats. The plasma glucose concentration being 883 uMole/100 ml in warm compared to 964 uMole/100 ml in cold conditions. However, there was no difference in the cold-acclimated rats, whether they were in the warm or in the cold.

The results of Depocas et al. (13) are quite similar. They used two groups of male Sprague-Dawley rats, one maintained at 30 degrees C and the other at 6 degrees C for eight weeks. Then each group was exposed for three hours at 30 degrees C and at 6 degrees C.

Exposure of warm-acclimated rats to the cold environment increased the plasma glucose concentration significantly ($p < 0.05$) from 136 to 161 mg/100 ml. Transfer of cold-acclimated rats to an environment at 30 degrees C resulted in no significant change in glucose concentration in the plasma.

However, with human subjects during exercise, the plasma glucose pattern seems to increase in heat. Rowell et al. (63) exposed eleven human subjects, aged from 21 to 26 years, to heat (46 to 48 degrees C). A level of exercise was chosen for the experiment which required forty-two to fifty-six per cent $\dot{M}VO_2$ and a H.R. of less than 150 beats/min at 25 degrees C. Subjects then exercised on a treadmill at 3.5 mph on grades ranging from 2.5 to 10% depending on the subjects' $\dot{M}VO_2$. Arterial glucose concentration rose from an average of 93 mg/100 ml at rest to 106 mg/100 ml at exhaustion.

Fink et al. (16) studied blood glucose concentration during exercise in the heat and cold. Six men, aged from 21 to 39 years, were subjects. The experiments were conducted in a chamber maintained either at 41 degrees C or at 9 degrees C. Exercise consisted of three fifteen minute cycling bouts at seventy to eighty-five per cent of the subject's aerobic capacity, with a ten minute period between each bout. In the 41 degrees C environment, plasma glucose was 80 mg/100 ml at rest and significantly ($p < 0.05$) increased to 87, 95 and 91 mg/100 ml respectively after the first, second and third fifteen minute cycling bouts. In the cold however, serum glucose showed a small decline ($p < 0.05$). The value at rest was 81 mg/100 ml and 76, 78 and 76 mg/100 ml respectively after the three exercise periods.

2. Free Fatty Acid (FFA)

Alexander et al. (1) exposed six lambs to a warm environment (29 degrees C) for one hour and, to a cold environment (-5 to -15 degrees C) for the next hour. Although changes in the FFA concentration showed considerable variability, the concentration clearly increased when the animals were exposed to cold. In the warm environment, FFA concentration was stable around 0.6 mEq/L for the whole hour of exposure, whereas it increased over 1.00 mEq/L when exposed to cold.

Quite similar results were found by Paul et al. (55, 56). Free fatty acid concentration was studied in five dogs in the basal state at 22 degrees C and during cold exposure at 4 to 5 degrees C. The experiment consisted in keeping dogs at rest for two hours at 22 degrees C. Then the room temperature was decreased over a period of sixty to ninety minutes to a new level of 4 to 5 degrees C which was maintained for an additional ninety to one hundred twenty minutes. Under the temperature of 22 degrees C the plasma FFA concentration was 0.605 uEq/ml. It increased to 1.018 uEq/ml during acute cold exposure.

Exposure to cold, with human subjects at rest, results in the same FFA pattern. Hanson et al. (24) exposed four subjects at rest to 0 degrees C for ninety minutes followed by a recovery period of four hours at 25 degrees C. The results showed that, at the end of the ninety minute period, the cold exposure plasma FFA were significantly ($p < 0.05$) higher. The over-all pattern of increased FFA levels after ninety minutes at 0 degrees C is followed by a

steady decline in the recovery period. The rest value of 630 uEq/L rose to 950 uEq/L after exposure to cold.

However, exercise under exposure to cold and heat environments appears to cause no significant effect on FFA levels. Fink et al. (16) found that although FFA showed a significant ($p < 0.05$) increase as a result of exercise there was no difference between the two experimental conditions. In the 41 degrees C environment plasma FFA was 0.29 mEq/L at rest and significantly increased to 0.35, 0.40 and 0.39 mEq/L levels respectively after the first, second and third fifteen minute cycling bouts. The results under cold exposure are quite similar since plasma FFA increased from 0.29 mEq/L to the values of 0.31, 0.33 and 0.41 mEq/L after the three exercise bouts respectively. In both environments the resting value was 0.29 mEq/L and rose to 0.39 and 0.41 mEq/L under heat and cold environments respectively.

3. Lactic Acid

The effects of cold exposure of animals on lactate level were studied by Alexander et al. (1). Lambs were held in a thermoneutrality chamber at 29 degrees C for one hour. The chamber was then cooled to between -5 and -15 degrees C and lambs exposed for another hour. In each of the six lambs, the concentration of lactate clearly increased, by two to three fold, when the animals were exposed to cold. Under thermoneutrality at 29 degrees C, blood lactate was quite stable around 20 mg/100 ml. This blood lactate concentration increased to 75 mg/100 ml under cold exposure.

In a study using human subjects, Rowell et al. (64) found that blood lactate concentration was slightly higher during work at 48.9 degrees C. Seven men were studied during exercise under heat stress. Blood lactate at 25.6 degrees C was compared with blood lactate after fifty minutes of prolonged treadmill work requiring forty-one to fifty-four per cent $\dot{M}VO_2$ at 48.9 degrees C.

Claremont et al. (10) found that blood lactate concentration was greater during exercise in heat compared to cold. Eight healthy male volunteers exercised on a bicycle ergometer on two separate occasions. The exercise work load required fifty-two to fifty-nine per cent of the subjects' $\dot{M}VO_2$ and had to be maintained for thirty minutes. On one occasion ambient condition was 34 degrees C and on the other occasion it was 0 degrees C. In the heat blood lactate level was 35.9 mg/100 ml whereas it was 26.5 mg/100 ml at 0 degrees C.

Fink et al. (16) found similar results. Blood lactate accumulation was roughly twice as great during the heat experiment as that measured during exercise in the 9 degrees C environment. These differences were found to be significant beyond the 0.01 level of confidence. The highest blood lactate concentration was around 50 mg/100 ml during exercise in the heat whereas it was around 27 mg/100 ml under cold environment.

4. Oxygen Consumption ($\dot{V}O_2$)

Acute cold exposure experiments have been conducted on normal dogs at rest (55, 56, 57). Paul et al. (55, 56) measured the effect of exposure to cold on $\dot{V}O_2$. In their experimental procedure, dogs were

first allowed a rest control period of two hours at 22 degrees C. This was followed by an exposure to cold at 4 to 5 degrees C for an additional two hours. The oxygen consumption per kilogram was 6.97 ml/kg/min at 22 degrees C and it increased to 10.04 ml/kg/min under 4 to 5 degrees C cold exposure. Those results were significantly different at the 0.001 level.

Pernod et al. (57) exposed fifteen dogs to cold ambient temperature (-25 degrees C). They were exposed at rest for a four hour period. The data used for the calculations was obtained during the last ninety minutes experimental period. Oxygen consumption rose from 5.5 ml/kg/min up to 40 ml/kg/min.

The effect of exposure to heat in humans, in a resting state, was studied by Consolazio et al. (11). The oxygen consumption of seven men, between the ages of 19 and 25, was measured at rest at three different levels of room temperature: 21.2, 29.4 and 37.7 degrees C. In this rest period, $\dot{V}O_2$ was 0.273, 0.282, and 0.304 L/min at 21.2, 29.4 and 37.7 degrees C, respectively. No significant difference was obtained in $\dot{V}O_2$ between the 21.2 and 29.4 degrees C temperatures. However, the $\dot{V}O_2$ at 37.7 degrees C was significantly higher.

In the same study they measured the effect of exercise under the same environmental temperatures on $\dot{V}O_2$. There were two levels of exercise work load: a fairly heavy work on the bicycle ergometer for fifty minutes requiring between 1.2 and 1.6 L/min and, another period of moderate exercise for fifty minutes requiring between 0.6 and 0.9 L/min. The oxygen consumption averaged 0.521, 0.525, and 0.590 L/min for the moderate work; and 1.422, 1.404, and 1.570 L/min of oxygen were used

for heavy work, for the 21.2, 29.4, and 37.7 degrees C test periods, respectively. Values for the 37.7 degrees C phase were significantly higher than those for the 21.2 and 29.4 degrees C phases.

However, William et al. (76) found that exercise under heat conditions reduced $\dot{V}O_2$. Three subjects acclimatized to severe heat pedaled at the determined load for different periods of time. Comparisons of oxygen intake values in comfortable (21 degrees C) and in heat (36 degrees C) conditions at levels of work less than the maximum were significantly ($p < 0.05$) different. Oxygen intake was significantly lower in hot than in comfortable conditions over quite a wide range of work rates in all three subjects.

The results of Brouha et al. (6) are in agreement with the previous finding. Eleven subjects performed in their experiments. The work consisted of pedaling a bicycle ergometer for thirty-four minutes: first at a submaximal work rate for thirty minutes, then without interruption at a maximal work rate for four minutes. The three environmental conditions were 25, 32.2 (humid), and 37.2 (dry) degrees C. The pre-exercise $\dot{V}O_2$ levels were 0.262, 0.274, and 0.254 L/min at 25, 32.2, and 37.2 degrees C, respectively. Then at the end of heavy load pedaling, $\dot{V}O_2$ values averaged 1.882, 1.776, and 1.611 L/min, respectively. The results at 37.2 degrees C were significantly ($p < 0.01$) lower than those of the two other temperatures.

In an attempt to determine whether $\dot{V}O_2$ is increased or decreased in hyperthermic exercising men, Rowell et al. (64) measured $\dot{V}O_2$ in fifty-four men under six different environmental conditions over a wide range of work intensities and durations. In each study the speed

and grade of the treadmill were set to provide the desired level of $\dot{V}O_2$ in terms of percentage of $M\dot{V}O_2$. The results revealed no significant effect of elevated temperature on $\dot{V}O_2$.

Likewise Pandolf et al. (51) tested four subjects at 24 and 45 degrees C. Oxygen consumption was determined during intermittent and prolonged exercise on a treadmill. The intermittent testing sessions consisted of eight cycles of ten minutes exercise and five minutes recovery. All subjects walked at 3.5 mph at a 7% to 9% grade which yielded approximately fifty per cent of their $M\dot{V}O_2$. Prolonged exercise was conducted continuously for ninety minutes. The time course of the oxygen uptake during the first and the eighth exercise-rest cycles of the two hours intermittent exercise in both neutral and hot ambient environments was practically the same. Also, $\dot{V}O_2$ obtained throughout the ninety minutes of prolonged exercise was the same for the neutral and the hot-dry environment.

In comparing the effect of cold (9 degrees C) and heat (41 degrees C) environmental stress on $\dot{V}O_2$ during exercise, Fink et al. (16) conducted experiments on six subjects. Exercise consisted of three fifteen minute cycling bouts at seventy to eighty-five per cent $M\dot{V}O_2$, with ten minutes rest between each. When compared with cold data, the results showed a significant ($p < 0.05$) increase in $\dot{V}O_2$ during exercise in the heat. At the end of each of the three fifteen minute cycling bouts, the $\dot{V}O_2$ was around 2.25 L/min at 9 degrees C and around 2.6 L/min under heat at 41 degrees C.

However, Claremont et al. (10) obtained contrary results. Eight subjects exercised on a bicycle ergometer for one half to one hour

at loads demanding fifty-two to fifty-nine per cent MVO_2, once at 0 degrees C and once at 35 degrees C. Despite identical ergometer load setting in both environments, a significant ($p < 0.01$) higher $\dot{V}O_2$ was observed during cycling in the cold. Mean values were 26.6 ml/kg/min in the heat and 29.7 ml/kg/min in the cold.

5. Minute Ventilation ($\dot{V}e$)

The effect of environmental temperature on respiration has been examined on pigs by Ingram et al. (35) and on sheep by Joyce et al. (41).

Ingram et al. (35) used eighteen pigs in their experiments. When observations were made on pigs exposed to a temperature below 30 degrees C, the animal was placed in the room for one hour before measurements were taken. At higher ambient temperatures, measurements were made as soon as the animal was settled in the stall.

Mean minute volume increased from 9 to 14 L/min in all animals exposed to temperatures between 0 and 25 degrees C as the temperature fell. Statistical analysis revealed that the correlation between ambient temperature and minute volume was significant ($p < 0.001$).

Minute volume also increased from an average of 10 to 30 L/min when pigs were exposed to ambient temperatures of 45 degrees C (dry bulb) and 25 degrees C (wet bulb). Minute volume increased with the rise in body temperature.

Joyce et al. (41) investigation on sheep resulted in similar results. They found that pulmonary ventilation increases at

both temperature extremes.

It seems that the effect of environmental temperatures during exercise has been investigated only under normal and heat conditions. Miller et al. (49) measured the effect of environmental temperatures during exercise on $\dot{V}e$ using four men partially acclimated to heat. The exercise consisted in a twelve minute progressive submaximal exercise on a bicycle ergometer. The subject was first exposed to the temperature condition, at rest for one hour, before moving across the cycle where he sat at rest for a further 10 min. He then commenced the twelve minute exercise at a pre-determined work load. The power output was raised from the initial by 10 W/min. This procedure was designated to ensure that the subject would reach about 70% of his peak performance during the final minute.

The results indicated that the effects of variation in dry bulb temperatures between 21 and 35 degrees C (50-65% relative humidity) increased minute ventilation. This increase was approximately linear and statistically significant ($p < 0.001$) with air temperature. It amounted an average 0.4% for each degree rise in dry bulb temperature.

Pandolf et al (51) studied $\dot{V}e$ during intermittent and prolonged exercise on a treadmill. As they found for $\dot{V}O_2$, $\dot{V}e$ at 24 degrees C did not differ in the heat at 45 degrees C (dry bulb). Minute ventilation values that were obtained throughout intermittent or continuous exercise were not significantly different from the neutral and the hot-dry environments.

In his experimental protocol, Brouha et al. (6) tested the effect of dry and warm environmental heat on $\dot{V}e$. After an exercise period

of 34 minutes (30 min. submaximal work rate and 4 min. maximal work rate), the $\dot{V}e$ value at normal room temperature (25 degrees C, 43% R.H.) was not significantly different from the $\dot{V}e$ at warm-dry conditions (37.2 degrees C, 25% R.H.). However, the $\dot{V}e$ before and after exercise under warm-humid conditions (32.2 degrees C, 82% R.H.) was significantly ($p < 0.05$) different when compared to normal temperature. This change observed was an increase in pulmonary ventilation. For normal, warm-dry and warm-humid temperatures, the average pre-exercise values for all eleven subjects were 7.73, 8.28 and 8.58 L/min, respectively. Similarly it was 43.75, 42.11 and 47.38 L/min, respectively immediately after exercise period.

6. Heart Rate (H.R.)

Frewin et al. (17) carried out experiments on five human subjects aged 18 to 42 years. After a rest period of thirty minutes in the experimental environment (10 or 40 degrees C) H.R. was recorded. Average H.R. at rest was 82 beats/min at 40 degrees C exposure whereas it was 66 beats/min under 10 degrees C environmental temperature exposure.

After the rest period exposure, the subjects then exercised on a treadmill, walking at a speed of 3.5 mph on a 8.6% grade for twenty minutes in the experimental environment (10 or 40 degrees C). Whereas H.R. in the heat was higher, results showed that exercise in the cold caused H.R. to increase by the same order of magnitude as seen at 40 degrees C. Mean H.R. increased from 82 to 119 beats/min in the heat and from 66 to 106 beats/min in cold environment.

Claremont et al. (10) and Fink et al. (16) found similar results and concluded that H.R. is significantly higher during exercise in the heat compared to standard and cold environments.

CHAPTER III

METHODOLOGY

Sample

Six male volunteers, 24 to 34 years of age, participated in the study: They were physical education students at the University of Alberta.

Testing Conditions

For the entire experiment, a vertical rod was fixed to the handle-bar of a Monark bicycle ergometer, in order to support the tubing system for oxygen consumption measurement. It was possible for the subject to move the vertical rod in a forward-backward direction. At the signal of the experimenter, one minute before the gas collection time, the subject pulled the vertical rod, adjusted the mouth piece and, put the noseclip on. This was done by the subject himself under supervision.

The gas collection was done by the simultaneous work of two experimenters. They were responsible for opening and closing two different valves. One which permitted inspired air to pass through the volume meter and the other which permitted expired air to enter a Douglas bag.

During the experimental sessions the subjects wore only shorts and footwear.

Maximal Oxygen Consumption Determination

Maximal oxygen consumption ($\dot{M}VO_2$) was established in a separate, preliminary test for each subject (48). Gas collection and analysis equipment included a Collins Triple-J valve, Douglas bags, a Beckman model E-2 oxygen analyser, and a KK Godart capnograph CO_2 analyser. Calibration of the apparatus was performed before use for each subject.

The test consisted in having the subject pedaling on a Monark bicycle ergometer. A ten minute warm-up at 450 kpm/min (50 rpm) was followed by a two minute rest period. The subject then pedaled at 750 kpm/min work load for four minutes. After a five minute rest period the work load was increased by 150 kpm/min and the subject pedaled for an additional four minute period. Expired air for the determination of $\dot{V}O_2$ was collected during the last minute of each work period. The procedure was continued until the subject was not able to continue or until the oxygen uptake, from one work period to another, declined. The highest $\dot{V}O_2$ for the subject was accepted as being the $\dot{M}VO_2$. Seventy-five per cent of the $\dot{M}VO_2$ was then calculated and the corresponding work load was used by the subject for the entire experiment.

Experimental Testing Procedure

The experiment consisted of twenty minutes of exercise on the bicycle ergometer at three different environmental temperatures, ($4^{\circ}C$, $21^{\circ}C$ and $40^{\circ}C$). Each subject was given a different order of

performing the three treatments; so all the possible permutations were used (Appendix A). Immediately before each experimental session, the room temperature, the barometric pressure and the relative humidity were recorded. The subject was then weighed and allowed a five minute rest period, while sitting on the bicycle ergometer at the temperature of the experimental treatment. This temperature was maintained for the whole testing session. A gas collection was made between the 4^{th} and the 5^{th} minute of rest and, a blood sample was taken at the end of the 5^{th} minute of rest. The exercise was then started with no warm-up at the predetermined work load (seventy-five per cent of the subject's $\dot{M}VO_2$) and maintained for twenty minutes at a frequency of 50 rpm.

Throughout the experimental session heart rate was recorded each minute with a Sanborn 500 Viso-Cardiette. Additional gas samples were taken between the 1^{st} and 2^{nd}, 6^{th} and 7^{th}, and the 19^{th} and 20^{th} minutes of exercise. The collection and the analysis were made using the procedure and apparatus as described above. Collection of expired air involved the use of four different Douglas bags with analysis taking place immediately at the end of the twenty minutes of exercise.

Three additional blood samples were taken at the end of the 2^{nd}, 7^{th}, and 20^{th} minutes of exercise. The blood samples were taken alternating arms of the subject by a laboratory technician at the end of the gas collection period. The tourniquet was put in place fifteen seconds before the end of the gas collection period. The subject was pedaling when the blood samples were taken. They were taken from the antecubital vein with a 10 ml vacutainer containing EDTA (Ethylene Diamine Tetra Acetate) as anticoagulant.

The blood samples were then immediately prepared to later undergo the appropriate biochemical analysis. The blood glucose was calorimetrically analyzed (67) at the end of the twenty minute exercise period, the plasma lactate level was measured (70) the day after the experimental session and total fatty acids were chromatographically analyzed (75) a month later.

Statistical Procedure and Experimental Design

The data was analysed using an analysis of variance: three-way classification. There were three levels of temperature treatment and four levels of time treatment. Each subject was tested under each of the temperature and time treatments. The simplest conceptualization of such a design is to consider subjects as an explicit dimension of the design; then each cell of the design contains one observation (12). There is, of course, no estimate of pure experimental error since, with one observation per cell, there is no within - cell variability in the data. Consequently, there is no appropriate denominator to form ratios for any of the effects involving subjects. The appropriate F ratios for the terms from the basic factorial design are: $MS_{A/MS_{AS}}$, $MS_{B/MS_{BS}}$, $MS_{AB/MS_{ABS}}$ (Table 1). Where the homogeneity conditions were not met, a conservative testing procedure (adjustment of degrees of freedom) for the within-subject effects was used (12). A Tukey (73) test was then calculated to determine the precise location of the significant differences in the study.

All computations were made with the IBM 360 computer at the University of Alberta. In all statistical analyses, the 0.1, 0.05 and 0.01 levels of significance are reported.

TABLE I

THREE-WAY ANOVA
MODIFIED STATISTIC CALCULATION FOR
REPEATED MEASURES ON SAME SUBJECT

SOURCE OF VARIATION	SS	DF	MS	F
'A' Main Effects	SS_A	1	MS_A	MS_A/MS_{AS}
'A*S' Interaction	SS_{AS}	5	MS_{AS}	
'B' Main Effects	SS_B	1	MS_B	MS_B/MS_{BS}
'B*S' Interaction	SS_{BS}	5	MS_{BS}	
'A*B' Interaction	SS_{AB}	1	MS_{AB}	MS_{AB}/MS_{ABS}
'A*B*S' Interaction	SS_{ABS}	5	MS_{ABS}	

CHAPTER IV

RESULTS AND DISCUSSION

Results

The statistical analysis summaries of the Three-Way Anova on each physiological parameter are presented in Appendix C. In Appendix D, statistical calculations for repeated measures on the same subjects are presented. The F values for 'A' main effects (Temperature), 'B' main effects (Time) and 'A*B' interaction are given. For the purpose of the discussion, three levels of significance were retained, that is, .01, .05, and .10.

1. Subjects

Six male subjects, 24 to 34 years of age, participated in this study. They were physical education students at the University of Alberta. In Table 2, the physical characteristics of the subjects involved in this experiment are presented. These values were measured at the time of the $\dot{M}VO_2$ test.

2. Plasma Glucose Concentration

The values of the plasma glucose level during exercise under different environmental temperatures are presented in Table 3. A different pattern occurred in cold as compared to hot and standard environments. Under cold stress, the glucose level decreased progressively from 87.0 to 76.5 mg/100 ml of plasma, whereas in hot and standard conditions it decreased until the seventh minute of exercise and then progressively increased until the exercise was

TABLE 2

SUBJECTS'PHYSICAL CHARACTERISTICS
(Means and Standard Deviations)
N = 6

	AGE YEARS	WEIGHT KG	$\dot{M}VO_2$ L/MIN	$\dot{M}VO_2$/KG L/MIN/KG	MAX $\dot{V}e$ L/MIN	MAX H.R. BEATS/MIN
MEANS	26.7	74.53	2.98	40.27	113.14	194.7
S.D.	3.40	5.73	0.38	6.19	18.92	16.08

TABLE 3

PLASMA GLUCOSE CONCENTRATION
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	87.0	85.0	83.0	86.5	83.5	81.8	84.2	76.8	79.7	76.5	83.0	83.7
S.D.	6.95	10.82	7.30	7.52	9.32	3.93	7.63	8.49	4.71	10.63	13.27	20.9

N.B. All measures in mg/100 ml

terminated after twenty minutes. However there were no significant differences in the results either for temperature or time effects.

3. Plasma Total Fatty Acid Concentration

There was no significant difference in plasma total fatty acid concentration in time or under the various temperature conditions. The results are presented in Table 4. Under the three environmental temperature conditions, there was a small but not significant tendency to increase from rest to the end of the twenty minute cycling exercise bout. Although higher plasma total fatty acid concentrations were found in heat than in cold, the differences were not statistically significant.

The results of per cent saturated and unsaturated plasma total fatty acid were similar to those of total fatty acid. Means and standard deviations are given in Tables 5 and 6 respectively for saturated and unsaturated fatty acids.

4. Plasma Lactic Acid Concentration

The plasma lactic acid results are presented in Table 7. The lactate level increased significantly ($p < 0.01$) during exercise in the three environmental temperatures. As shown in Figure 1 the highest values were obtained under hot and cold stresses at the end of the twenty minute exercise bout. Plasma lactate levels were 63.5 and 64.7 mg/100 ml respectively. The lactate level at twenty minutes under standard environment was slightly lower than hot and cold conditions. It was 49.2 mg/100 ml of plasma. However no significant difference was

TABLE 4

PLASMA TOTAL FATTY ACID CONCENTRATION
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	3.23	3.18	3.88	3.34	3.45	3.98	3.42	3.83	4.22	3.47	3.63	4.39
S.D.	0.63	1.26	1.59	0.80	1.45	1.50	0.87	2.00	2.11	0.87	1.36	2.04

N.B. All measures in mg/ml plasma

TABLE 5

PER CENT SATURATED TOTAL PLASMA FATTY ACID
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	34.3	35.8	36.7	34.6	36.4	36.1	34.4	36.6	36.7	34.1	36.1	36.2
S.D.	0.99	3.04	3.19	1.29	2.20	3.57	1.29	2.96	2.85	1.25	3.34	2.63

TABLE 6

PER CENT UNSATURATED TOTAL PLASMA FATTY ACID
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	65.7	64.2	63.3	65.4	63.6	63.9	65.6	63.4	63.3	65.9	63.9	63.8
S.D.	0.99	3.04	3.19	1.29	2.20	3.57	1.29	2.96	2.85	1.25	3.34	2.63

TABLE 7

PLASMA LACTIC ACID CONCENTRATION
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	8.2	8.7	7.3	16.9	14.7	12.8	34.3	33.7	39.3	64.7	49.2	63.5
S.D.	1.37	3.54	2.19	2.79	2.51	5.39	11.40	11.48	9.74	20.25	27.18	21.44

N.B. All measures in mg/100 ml plasma

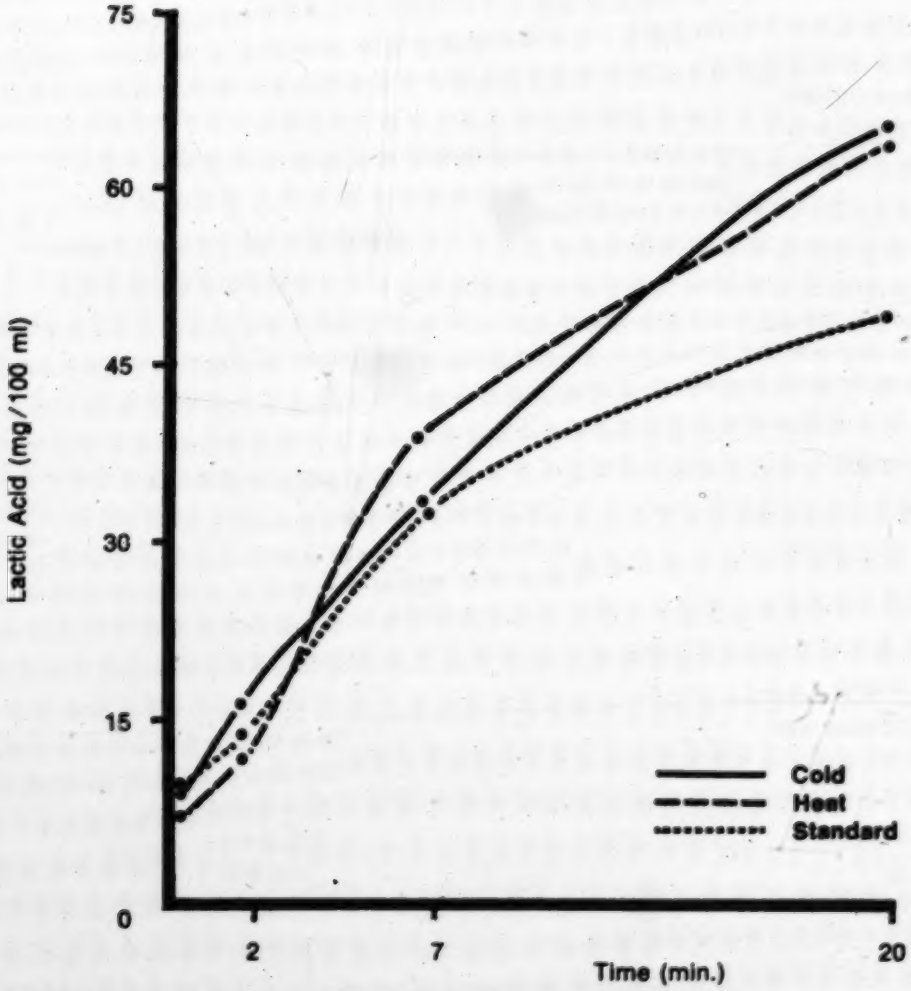

Figure 1: The effect of acute exercise on plasma lactic acid concentration under three different environmental temperatures.

found between the three temperature conditions. From Figure 1 it also appears that no steady state in plasma lactic acid concentration was reached during exercise under the three temperature conditions as the lactate level increased progressively through the exercise sessions.

5. Oxygen Consumption ($\dot{V}O_2$)

The oxygen consumption results are presented in Table 8. Oxygen consumption increased significantly ($p < 0.01$) during exercise under the three environmental temperature conditions. As shown in Figure 2 there was a fast increment from rest to two minutes of exercise and in the following minutes a steady state was reached and maintained for the remaining time of exercise. At rest, for cold, standard and hot conditions it was 0.35, 0.25 and 0.32 L/min respectively. After two minutes of exercise values of 2.01, 1.84 and 1.62 L/min were recorded. However temperature had no significant effect on $\dot{V}O_2$ during exercise.

Nevertheless when $\dot{V}O_2$ results were computed per kilogram of body weight a significant ($p < 0.1$) difference appears between cold results and the two other temperatures. The means of $\dot{V}O_2$/kg under cold were uniformly higher as shown in Table 9. The time course of $\dot{V}O_2$/kg during exercise under the three temperatures is presented in Figure 3. The highest mean value under cold was 31.58 ml/min/kg after seven minutes of exercise. For standard and heat conditions it was 26.62 and 27.38 ml/min/kg respectively after twenty minutes of exercise.

TABLE 8

OXYGEN CONSUMPTION ($\dot{V}O_2$)
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	0.35	0.25	0.32	2.01	1.84	1.62	2.36	1.91	1.98	2.32	2.01	2.06
S.D.	0.14	0.07	0.13	0.26	0.33	0.35	0.29	0.59	0.31	0.55	0.43	0.24

N.B. All measures in L/min

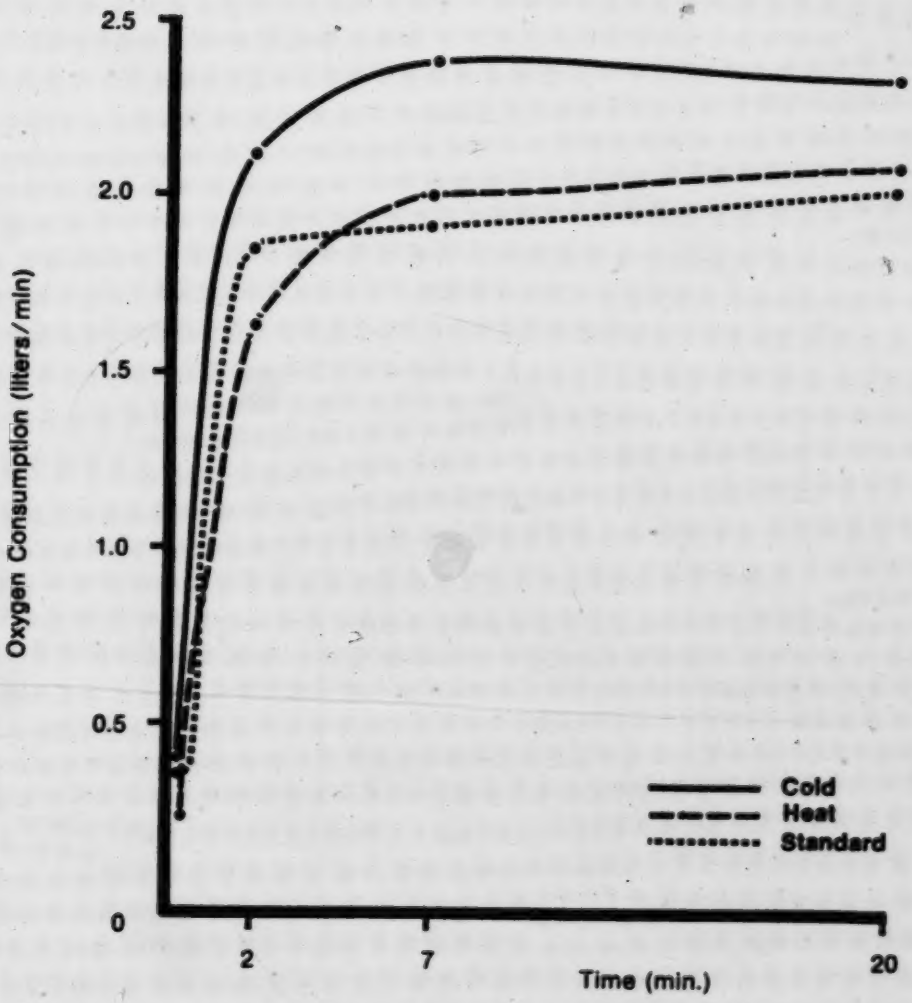

Figure 2: The effect of acute exercise on oxygen consumption under three different environmental temperatures.

TABLE 9

OXYGEN CONSUMPTION PER KILOGRAM ($\dot{V}O_2$/kg)
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	4.65	3.23	4.27	26.73	24.47	21.52	31.58	25.23	26.13	30.65	26.62	27.30
S.D.	1.85	0.98	1.97	2.55	3.63	4.78	3.14	6.82	3.23	5.79	5.16	3.50

N.B. All measures in L/min/kg

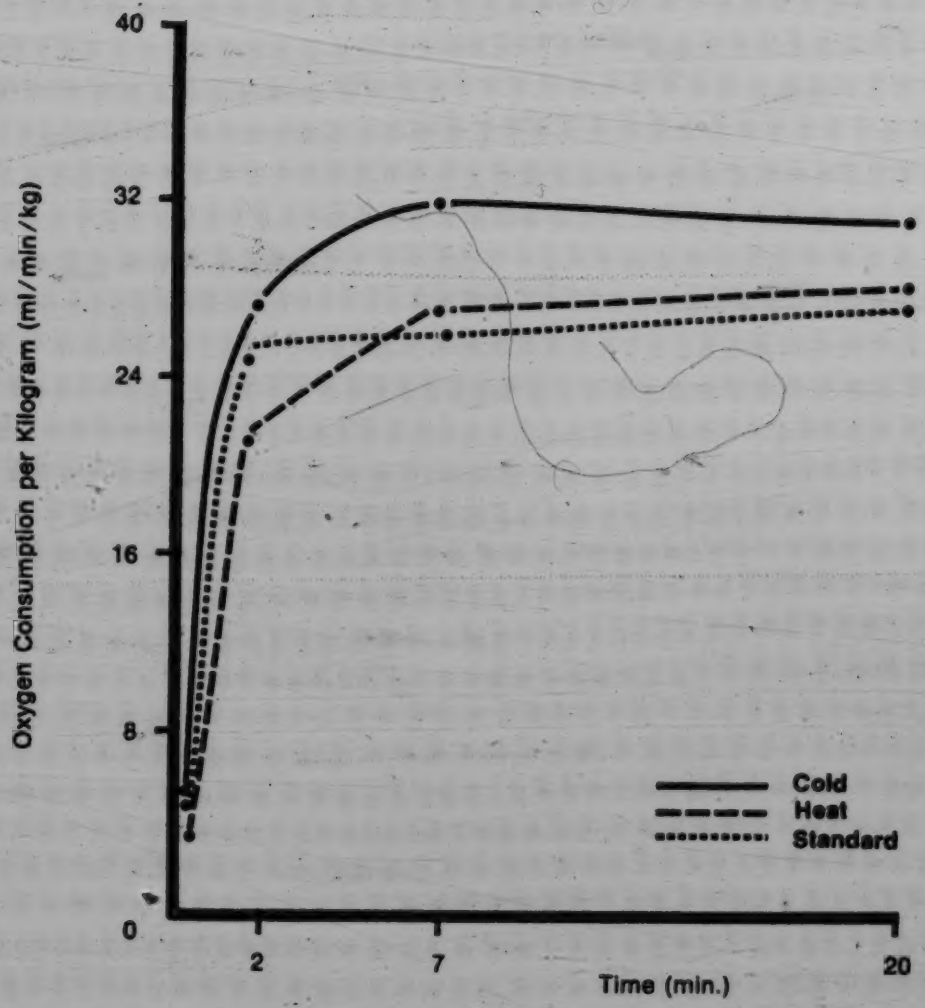

Figure 3: The effect of acute exercise on oxygen consumption per kilogram under three different environmental temperatures.

6. Minute Ventilation ($\dot{V}e$)

As a result of exercise, there was a significant ($p < 0.01$) change in $\dot{V}e$ between pre-exercise and end of work values. This is illustrated in Figure 4. Minute ventilation increased continuously through the exercise sessions and no steady state was attained. The pre-exercise values were 19.35, 18.92 and 16.77 L/min respectively for cold, standard and hot conditions. The corresponding end of work values were 85.15, 77.59 and 90.45 L/min respectively. These values are presented in Table 10. However temperature had no significant effect on $\dot{V}e$ level during exercise. Minute ventilation values were similar at rest and at the second, seventh and twentieth minutes of exercise under the three environmental temperature conditions.

7. Heart Rate (H.R.)

As illustrated in Figure 5, H.R. increased drastically ($p < 0.01$) through exercise. This increase was very rapid between rest and two minutes of exercise. Under the three environmental temperatures it was between 80 to 100 beats/min at rest and it increased to 148 to 157 beats/min after two minutes. After the twenty minute exercise sessions it was 171 to 191 beats/min under the different experimental conditions. No true steady state was attained. Moreover, H.R. under hot stress was significantly ($p < 0.05$) different from cold and standard conditions. As shown in Table 11, the highest value was always under hot environment. There was no significant difference between cold and standard environmental conditions.

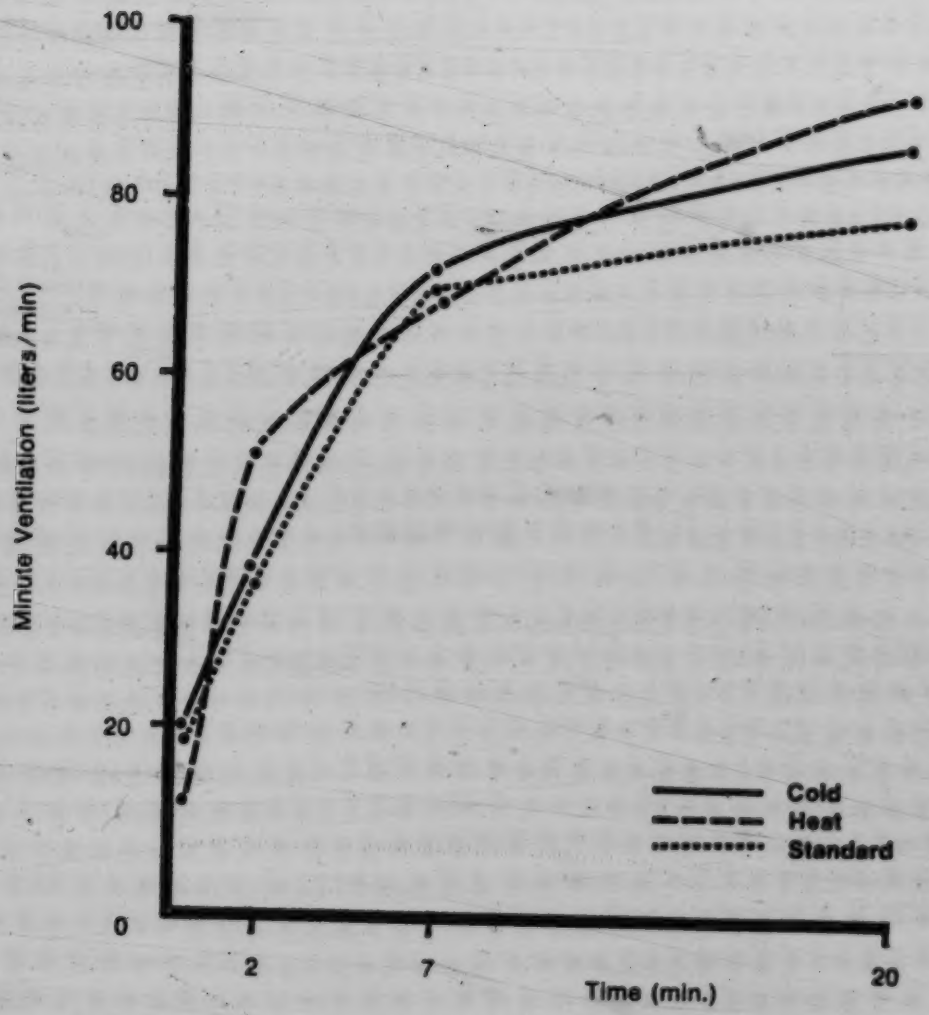

Figure 4: The effect of acute exercise on ventilation under three different environmental temperatures.

TABLE 10

MINUTE VENTILATION ($\dot{V}e$)
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	19.35	18.92	16.77	37.88	36.65	51.48	71.79	69.01	68.35	85.15	77.59	90.45
S.D.	4.86	7.23	3.66	6.16	6.05	4.90	11.85	13.84	11.28	21.85	23.71	15.19

N.B. All measures in L/min

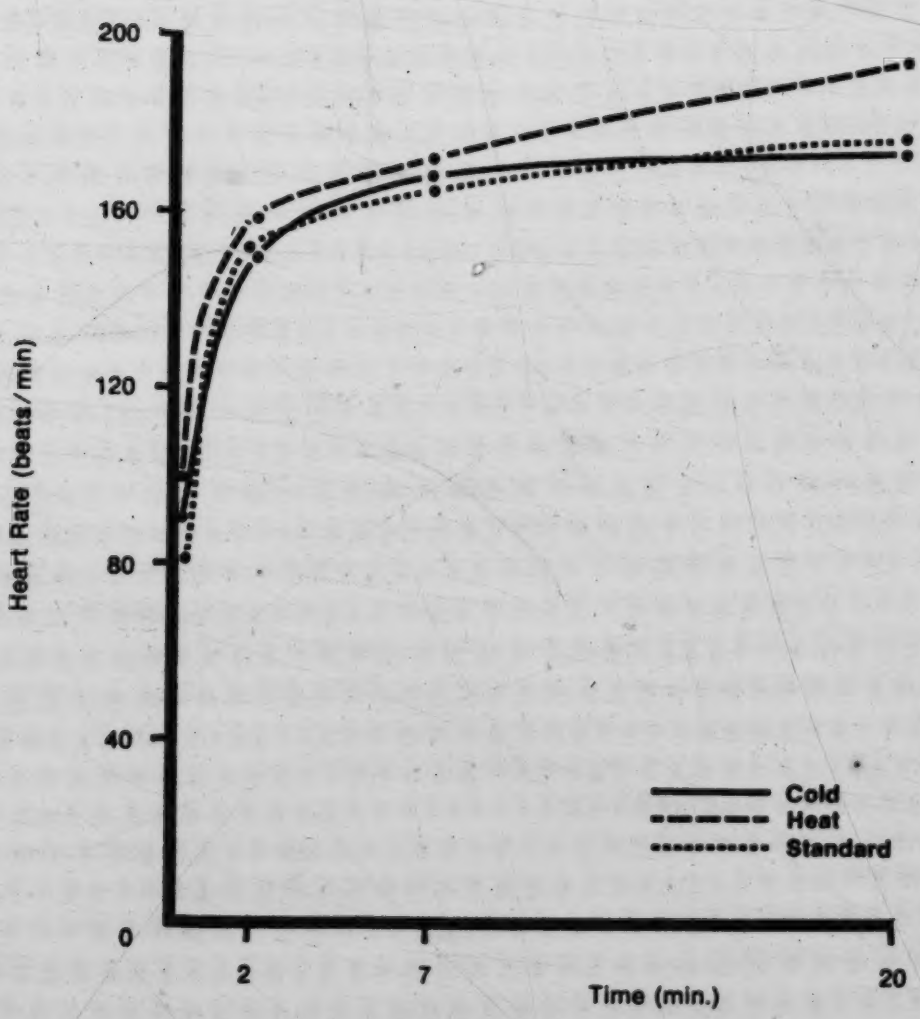

Figure 5: The effect of acute exercise on heart rate under three different environmental temperatures.

TABLE 11

HEART RATE
(Means and Standard Deviations)
N = 6

	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
MEANS	84.5	80.0	99.7	148.2	149.2	157.3	165.3	163.2	168.8	171.2	173.7	191.5
S.D.	9.85	12.21	10.77	5.84	9.79	7.93	10.14	12.01	9.34	11.26	9.60	12.80

N.B. All measures in beats/min

Discussion

The aim of this research was to observe how some physiological parameters react to exercise under various environmental temperatures. In this regard a discussion of physiological reactions under normal environment will follow. These normal reactions are used as references for comparison with hot and cold reactions which will be discussed later.

1. Reactions Under Normal Environmental Temperature

The liver is the most prominent source of blood glucose (47) and it is also able to respond rapidly to changes of glucose concentration in the portal vein. When the portal vein blood contains a high concentration of glucose, the liver removes glucose from the blood but, when the concentration is low, the liver releases glucose into the blood. It appears that the rate of release and the rate of peripheral removal of glucose are under strict hormonal controls (38, 53). In this control, insulin plays the major role by decreasing blood glucose levels (38).

The central pathway of carbohydrate catabolism in most cells, is the conversion of glucose to pyruvate catalyzed by the glycolytic enzymes under aerobic or anaerobic conditions. A stress condition such as exercise is known to increase muscle cell permeability to glucose, possibly by the same mechanism as insulin (30, 60). This muscle cell permeability seems to cause a rapid fall in the level of blood glucose (22, 34), and this reduction of blood glucose concentration, stimulates the liver to release glucose into the blood. From this increase in

glucose mobilization the turnover rises and its participation in exercise metabolism also increases. Glucose permeability, and therefore the glucose uptake, seems to be the rate limiting factor in the glucose supply to the working muscle.

The point at which subjects exhibit a changeover from a decrease to an increase in blood glucose concentration at exhaustion appears to lie between seventy and eighty per cent of the $\dot{M}VO_2$ as measured on the bicycle ergometer (59). Thus the critical experiments are those at/or near the seventy-five per cent $\dot{M}VO_2$ level.

Mobilization of fatty acids is known to occur in higher animals in response to both psychological and physiological stresses. Such conditions result in an elevation of the plasma FFA level and this implies an increased mobilization of fatty acids. The available evidence strongly suggests that this mobilization is caused directly or indirectly by epinephrine, norepinephrine, growth hormone, and hypoglycemia (50). However there are other factors which may inhibit the FFA mobilization. Two of these factors are an increase in blood lactic acid concentration and a reduction in blood pH. Those regulatory mechanisms which affect the plasma FFA level positively or negatively work the same way. They do so by controlling the rate of release of FFA (lipolysis) rather than the rate of uptake (38).

During light exercise as long as the oxygen supply is adequate, the FFA release increases and few of the FFA are activated for re-esterification. Consequently the FFA turnover rate and the FFA oxidation rate increase with the aerobic work load but, the percentage of total energy derived from plasma FFA oxidation will be the same (54).

When work is performed above the physical capacity of the individual, the oxygen supply is inadequate and anaerobic glycolysis occurs. Thus the lactic acid concentration increases and the energy supply derived from FFA cannot cope with this increased work load. It would be a logical assumption that during heavy work, when the blood lactate quickly rises, the elevated lactate level itself depresses the release of FFA from the adipose tissue (36, 37, 38). The re-esterification prevails, and the turnover rate of FFA decreases (38).

Exercise is also known to alter the concentration of some plasma-lipids (7, 16, 62). Investigation into the effect of exercise on the plasma-lipids has so far been most concerned with changes in the concentration of the total lipids fractions. By contrast, the fatty acids contained within these fractions have received relatively little attention. However, it appears possible that a preferential muscular oxidation of the unsaturated acids takes place. As with the FFA, there seems to be a preferential oxidation of unsaturated components in the complex lipids (23, 32, 71).

In aerobic conditions lactate concentration does not increase because an equilibrium exists in the reaction between pyruvate and lactate. However under anaerobic conditions, as during vigorous exercise, there is an increase in lactate concentration to very high values (50). Under anaerobic conditions the major proportion of the pyruvic acid is converted into lactic acid, which diffuses readily out of the cells into the extracellular fluids. There is an increased lactate concentration in the blood, and removal of lactate by the liver is the main mechanism by which blood lactate can return to a normal level.

It is well known that $\dot{V}O_2$, $\dot{V}e$ and H.R. increase with increasing work loads (3, 4, 74). This is to cope with the energy demand of muscular work.

In the present experiment the subjects were exercised at seventy-five per cent of their individual $M\dot{V}O_2$ and no time effects on the blood glucose concentration were demonstrated. As mentioned by Pruett (59), the $M\dot{V}O_2$ level used in this study was critical for a decrease to an increase in blood glucose concentration.

However in this experiment a principal orientation was to study FFA variations during exercise under thermal stress. But by a misleading communication total fatty acid was analysed instead of plasma FFA. Therefore the results are devoid of meaning in an energy sources point of view, because it is in a FFA form that lipids are used for muscular work. Moreover, this mistaken analysis, provides most important individual fatty acid composition in the total plasma fatty acid. However, this knowledge is not of great utility because one does not know in which of the lipid fractions the modification may or may not have occured.

Blood lactate increased but not to very high values. We can therefore assume that most of the energy derived was from aerobic sources. The steady state in $\dot{V}O_2$ between the second minute and the end of the work session confirms the aerobic conditions which prevail at seventy-five per cent of individual $M\dot{V}O_2$.

Minute ventilation and H.R. increased and this is in agreement with previous studies.

2. Reactions Under Hot and Cold Environmental Temperatures

Although Rowell et al. (63) and Fink et al. (16) found a significant increase in blood glucose level at elevated environmental temperatures, no significant increase in blood glucose concentration from rest to end of work under the three environmental temperatures were found in the present study. Because Fink et al. (16) used a procedure which is very similar, a comparaison of the results is presented in Table 12. The number of subjects and the per cent individual $\dot{M}VO_2$ were the same; the temperature and duration of exercise were very close. They found a significant ($p < 0.05$) increase in the heat and a statistically significant ($p < 0.05$) decrease in the cold. In the present research, blood glucose level was stable under hot condition and decreased (not significantly) under cold. As shown in Table 3 the subjects'standard deviation of the mean in the present study showed a great variability and probably accounted for this non significant difference.

There are various stimuli which may affect the amount of FFA oxidized. Ambient temperature is one of those stimuli and cold has been especially studied. During a period of stress induced by acute cold exposure, FFA mobilization and utilization will remain unchanged or slightly increased if the initial level is high prior to exposure. However, if the initial level is low, mobilization and utilization will drastically increase (56).

The increases in FFA levels are due to enhanced lipolitic activity potentiated by norepinephrine (1, 5, 17, 24, 29, 56).

TABLE 12

COMPARED RESULTS OF DIFFERENT PARAMETERS
(Means)

AUTHOR	NUMBER OF SUBJECTS	TEMPERATURES USED		END OF WORK*					
				GLUCOSE mg/100 ml		LACTATE mg/100 ml		$\dot{V}O_2$ L/min	
		COLD	HEAT	COLD	HEAT	COLD	HEAT	COLD	HEAT
Fink et al. (15)	6	9°C	41°C	(81.0) 76.0	(80.0) 87.0	(11.0) 27.0	(09.0) 52.0	( ) 2.25	( ) 2.60
Godin	6	4°C	40°C	(87.0) 76.5	(83.0) 83.7	(08.2) 64.7	(07.3) 63.5	(0.35) 2.32	(0.32) 2.06

* First 15 minute cycling bout at 75% $M\dot{V}O_2$ (Fink et al.)
End of 20 minute cycling session at 75% $M\dot{V}O_2$ (Godin)

N.B. Rest values are presented between parentheses.

Elevated concentrations of FFA in the plasma certainly provide a suitable substrate for increased body heat production during acute cold exposure (24). Its appears that the principal, but not the only, substrate utilized during cold exposure is lipid. Fink et al. (16) found no significant difference in the FFA level during exercise under heat and cold environment.

In studies on the composition of the plasma lipids it became evident that accurate data concerning the range and normal variations of the individuals'plasma fatty acid during exercise under various temperatures was not available.

Once more the present results are really different and can not be compared. However no significant difference in total plasma fatty acids during exercise under cold, standard and heat environments were found in the present study. Saturated and unsaturated total plasma fatty acid was also non significant.

Blood lactate concentration increases above normal in lambs and dogs (1, 9), during cold-exposure. The increase in plasma lactate in cold-exposed lambs is almost due to stimulation of the sympathetic system by cold exposure, since it is mimicked when catecholamines are infused into lambs under thermoneutral conditions (1). However, in the range of growing energy output, anaerobiosis is more quickly manifested by muscular exercise than by shivering reaction in the dog (9).

Blood lactate concentration increases during work in the heat (10, 16, 63, 64). When increases do occur, hepatic lactate removal can be reduced by heat stress and/or muscle anaerobic glycolysis increase which presumably would elevate lactate levels by a mass action effect (10, 63).

In the present experiment no significant difference in plasma lactate level between the three temperature conditions was found. Considering the results presented in Table 7 and illustrated in Figure 1, one can note a non significant tendency for the lactate level to be lower in standard conditions. As it was for glucose, subjects reacted differently to thermal stress and an important standard deviation in statistical analysis appeared. When the results in Table 12 are compared with Fink et al (16), it is surprising to note the big difference in the lactate level at end of work even if the time of work was five minutes longer in the present study. They found a significantly ($p < 0.01$) higher lactate concentration under heat environment when compared with a cold lactate level.

Literature is divided on whether $\dot{V}O_2$ increases (11, 14), decreases (6, 46, 76) or remains unchanged by heat stress (69, 78). Multiple measurements of $\dot{V}O_2$ under different environmental conditions, over a wide range of work intensities and durations, revealed no significant effect of elevated temperature on $\dot{V}O_2$ (51, 64).

These results may be explained by the increased mechanism efficiency of the muscle when its temperature is elevated. If true, this increase in efficiency appears to reduce $\dot{V}O_2$ by an amount equal to or greater than the increment which should result from physical changes within the cells as a function of increased body temperature (64).

Even if resting cold-exposure increased $\dot{V}O_2$ (55, 56, 57), it is not clear if exercise in cold environment increased or decreased $\dot{V}O_2$. Nevertheless, the results of the present study, as those of Claremont et al. (10) reflect a tendency to measure a higher $\dot{V}O_2$ during exercise

in cold conditions. Again, if the results of the present study are compared with those of Fink et al. (16) it can be noted in Table 12 that the latter recorded a significant ($p < 0.05$) increase in $\dot{V}O_2$ under hot temperature whereas a significant ($p < 0.1$) increase in $\dot{V}O_2$/kg under cold environment only is found in the present work. As mentioned by Claremont et al. (10) the catecholamine calorigenic effect observed by others (5, 20) during exposure to cold may be the cause for this higher $\dot{V}O_2$ since it is not due to a higher work load. Claremont et al. (10) and Fink et al. (16) determined if there was a difference in work load under different environmental temperatures and if the $\dot{V}O_2$ difference between conditions was due to a temperature effect on the bicycle resistance mechanism. They found no significant difference in the work load under cold and heat conditions.

Under extreme environmental temperature exposure, $\dot{V}e$ increases. The increase in minute ventilation at low ambient temperature may be necessary to meet the demand for extra oxygen related to an increase in metabolism (35, 41). Under heat conditions the steady increase in minute ventilation rate is achieved through an increase in frequency of breathing. This is because animals adjust their respiration in response to thermal stress for increase in evaporative heat-loss (35, 41). However, as shown by Brouha et al. (6) the increase in $\dot{V}e$ during exercise under heat stress seem to be related to an elevated degree of relative humidity (R.H.).

The present results are in agreement with the preceding conclusions. No significant temperature effect on $\dot{V}e$ was found. The relative humidity in the testing sessions averaged twenty per cent in the heat (Appendix B).

The increment in H.R. is greater under heat stress (52, 65, 69). It appears that this higher H.R. in the heat may help to maintain cardiac output whereas skin blood flow is elevated for temperature regulation (10, 76). This could explain the subjects'greater sensation of fatigue in the heat experiments.

In addition to air temperature, there are, of course, other factors such as ambient water vapor pressure, air movement, radiant heat load, etc..., which influence thermal balance (64). In the present work no attempt were made to analyse responses with respect to these variables. Hot-dry and hot-humid environments represent greater thermal stresses for men as the capacity for evaporative cooling in the environment conditions becomes reduced (52, 66). The decrease in time tolerance may be closely associated with an impaired physical capacity for evaporative cooling (33, 52, 77). As the ambient vapor pressure increases in hot environments, the cooling capacity rapidly decreases. The elevated ambient vapor pressure impairs evaporative cooling on the skin, thus increasing the burden on the circulatory system to transport heat from the central core to the skin surface to maintain a normal internal body temperature (52, 66).

It can be concluded, as reported by Rowell et al. (63) in the presentation of their results:

> "As previously demonstrated for central circulatory and thermal responses, individual variability in response to a given thermal plus exercise stress was large-even when work required similar fractions of maximal oxygen intake". (63, p. 478).

CHAPTER V

SUMMARY AND CONCLUSIONS

The effects of exercise under different environmental temperatures on some physiological parameters was studied using a group of six physical education students. After a $\dot{M}VO_2$ test, seventy-five per cent of the individual aerobic capacity was used as the work load for the study. Each subject had to exercise for twenty minutes under three different environmental temperatures which were $4^{\circ}C$, $21^{\circ}C$ and $40^{\circ}C$. The parameters measured were as follows: blood glucose concentration, plasma total fatty acid concentration, per cent saturated and unsaturated fatty acids, plasma lactic acid level, $\dot{V}O_2$, $\dot{V}e$, and H.R.

Even though the mean plasma glucose level decreased progressively in cold at rest, there was no significant exercise effect. There was also no significant difference in the results between the three environmental temperature conditions.

Plasma total fatty acid concentrations were similar under the three environmental temperatures. Also, no significant exercise effects were recorded. The conclusions concerning plasma saturated or unsaturated total fatty acids were the same.

The plasma lactic acid level increased significantly ($p < 0.01$) during exercise in the three environmental temperatures and no steady state was reached. However, no significant differences were found between the three temperature conditions.

Oxygen consumption increased significantly ($p < 0.01$) during exercise under the three environmental temperature conditions.

However no significant differences were found between the three temperatures. Nevertheless, when $\dot{V}O_2$ results were computed per kilogram of body weight, a significant ($p < 0.1$) difference appeared between cold results and the two other temperatures. The oxygen consumption per kilogram was elevated under cold stress.

Exercise had a significant ($p < 0.01$) effect on the $\dot{V}e$ level. However, temperature had no significant effect on the $\dot{V}e$ level during exercise.

Heart rate increased drastically ($p < 0.01$) through exercise. Under heat stress, H.R. was significantly ($p < 0.05$) different from cold and standard conditions. The highest values were always recorded in the hot environment.

From the results obtained, it is very difficult to generalize about environmental temperature effects during exercise. Subjects seemed to react differently to exercise plus thermal stress. There are at least three factors which may have affected the results of this research. First, subjects were cold-acclimated since testing sessions were held in the months of March and April, which is early in the springtime. Second, the subjects' diets were not controlled even though the subjects were asked to present themselves at each session in a fasting state. Third, subjects were tested at different times of the day because of the availability of the different testing chambers (cold and hot).

For future research, using the same experimental design, it would be preferable to use more subjects divided into three different groups with each group being tested under a different environmental temperature condition. Also, a measure of FFA level should be very

interesting from an energy utilization point of view. It would also be important to know the proportion of various saturated and unsaturated fatty acids which composed FFA since a preferential use of plasma unsaturated fatty acids by the working muscles seemed to exist.

Finally, body temperature measurements taken during the exercise sessions would be helpful in the discussion of results.

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APPENDIX A

TESTING SCHEDULE

TESTING SCHEDULE

TEMPERATURE	21°C	40°C	21°C	4°C	4°C	21°C	40°C	21°C
TESTING DATE	March 21	March 24	March 26	March 28	March 29	April 3	April 7	April 9
SUBJECT								
A.T.					X	X	X	
A.L.		X		X		X		
G.T.	X	X		X				
J.J.					X		X	X
R.F.	X			X			X	
S.G.		X	X		X			

APPENDIX B

ENVIRONMENTAL PHYSICAL CONDITIONS

ENVIRONMENTAL PHYSICAL CONDITIONS
IN COLD CONDITIONS

SUBJECTS	TEMPERATURE °C	DRY BULB °C	WET BULB °C	RELATIVE HUMIDITY %	BAROMETRIC PRESSURE mm Hg	WATER VAPOR TENSION mm Hg
A.T.	4	5.0	4.0	84	700.75	5.124
A.L.	5	7.0	5.5	82	696.50	4.633
G.T.	5	4.5	3.0	75	693.75	4.238
J.J.	4	4.0	3.0	87	700.50	5.337
R.F.	4	5.0	4.0	84	702.00	5.124
S.G.	4	4.0	3.0	83	696.75	5.063
MEANS	4.3	4.9	3.75	82.5	698.375	4.920
S.D.	0.516	1.114	0.987	4.037	3.1843	0.4062

ENVIRONMENTAL PHYSICAL CONDITIONS
IN STANDARD CONDITIONS

SUBJECTS	TEMPERATURE °C	DRY BULB °C	WET BULB °C	RELATIVE HUMIDITY %	BAROMETRIC PRESSURE mm Hg	WATER VAPOR TENSION mm Hg
A.T.	20.5	19.5	10.5	30	703.6	5.415
A.L.	21.0	19.5	10.5	30	704.2	5.580
G.T.	21.0	21.0	9.0	15	702.8	2.790
J.J.	21.5	19.5	11.5	37	702.8	7.104
R.F.	21.0	19.0	9.0	21	703.0	3.906
S.G.	21.5	22.0	9.5	12	701.1	2.304
MEANS	21.1	20.1	10.0	24.2	702.9	4.516
S.D.	0.376	1.158	1.000	9.745	1.039	1.8375

ENVIRONMENTAL PHYSICAL CONDITIONS
IN HEAT CONDITIONS

SUBJECTS	TEMPERATURE °C	DRY BULB °C	WET BULB °C	RELATIVE HUMIDITY %	BAROMETRIC PRESSURE mm Hg	WATER VAPOR TENSION mm Hg
A.T.	40	37.0	21.0	23	704.0	12.166
A.L.	38	36.0	19.0	18	703.8	7.455
G.T.	39	36.5	19.0	17	703.8	7.860
J.J.	39	35.5	20.5	24	704.0	12.576
R.F.	39	38.0	19.0	14	703.7	6.812
S.G.	40	38.0	21.0	20	704.0	11.610
MEANS	39.2	36.8	19.9	19.3	703.9	9.747
S.D.	0.753	1.033	1.021	3.777	0.000	2.6364

APPENDIX C

SUMMARIES OF THREE-WAY ANALYSIS OF VARIANCE ON SOME PHYSIOLOGICAL PARAMETERS

GLUCOSE
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	35.027	2	17.513	0.19151	0.82671
"B" MAIN EFFECTS	280.777	3	93.592	1.02342	0.39615
"A*B" INTERACTION	432.305	6	72.050	0.78786	0.58641
"S" MAIN EFFECTS	1377.777	5	275.555	3.01315	0.02547
"A*S" INTERACTION	2222.472	10	222.247	2.43023	0.02937
"B*S" INTERACTION	1203.888	15	80.259	0.87762	0.59340
"A*B*S" INTERACTION	2743.527	30	91.450		

TOTAL FATTY ACID
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	7.579	2	3.789	42.27767	0.00000
"B" MAIN EFFECTS	2.029	3	0.676	7.54727	0.00067
"A*B" INTERACTION	0.481	6	0.080	0.89415	0.51507
"S" MAIN EFFECTS	105.851	5	21.170	236.19541	0.00000
"A*S" INTERACTION	15.597	10	1.560	17.40132	0.00000
"B*S" INTERACTION	3.178	15	0.212	2.36420	0.02221
"A*B*S" INTERACTION	2.689	30	0.090		

SATURATED TOTAL FATTY ACID
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	61.841	2	30.921	22.64474	0.001
"B" MAIN EFFECTS	1.766	3	0.589	0.43110	n.s.
"A*B" INTERACTION	2.871	6	0.478	0.35044	n.s.
"S" MAIN EFFECTS	237.876	5	47.575	34.84176	0.001
"A*S" INTERACTION	81.751	10	8.175	5.98702	0.001
"B*S" INTERACTION	29.521	15	1.968	1.44134	n.s.
"A*B*S" INTERACTION	40.964	30	1.365		

UNSATURATED TOTAL FATTY ACID
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	61.361	2	30.680	22.56174	0.001
"B" MAIN EFFECTS	1.889	3	0.63	0.46315	n.s.
"A*B" INTERACTION	2.805	6	0.467	0.34376	n.s.
"S" MAIN EFFECTS	237.360	5	47.472	34.90992	0.001
"A*S" INTERACTION	81.719	10	8.172	6.00945	0.001
"B*S" INTERACTION	29.546	15	1.970	1.44848	n.s.
"A*B*S" INTERACTION	40.795	30	1.360		

LACTIC ACID
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	301.465	2	150.732	2.38111	0.10970
"B" MAIN EFFECTS	28670.707	3	9556.902	150.96983	0.00000
"A*B" INTERACTION	765.395	6	127.565	2.01515	0.09466
"S" MAIN EFFECTS	4287.734	5	857.546	13.54662	0.00000
"A*S" INTERACTION	991.200	10	99.120	1.56579	0.16533
"B*S" INTERACTION	4988.039	15	332.535	5.25305	0.00006
"A*B*S" INTERACTION	1899.101	30	63.303		

OXYGEN CONSUMPTION
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	1.024	2	0.512	3.73158	0.03571
"B" MAIN EFFECTS	40.199	3	13.399	97.63174	0.00000
"A*B" INTERACTION	0.441	6	0.073	0.53627	0.77632
"S" MAIN EFFECTS	1.779	5	0.355	2.59353	0.04592
"A*S" INTERACTION	1.361	10	0.136	0.99210	0.47144
"B*S" INTERACTION	1.043	15	0.069	0.50683	0.91723
"A*B*S" INTERACTION	4.117	30	0.137		

OXYGEN CONSUMPTION PER KILOGRAM
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	201.450	2	100.725	4.23692	0.02395
"B" MAIN EFFECTS	7093.589	3	2364.529	99.46220	0.00000
"A*B" INTERACTION	83.823	6	13.970	0.58767	0.73740
"S" MAIN EFFECTS	95.897	5	19.179	0.80677	0.55396
"A*S" INTERACTION	244.522	10	24.452	1.02856	0.44406
"B*S" INTERACTION	89.659	15	5.977	0.25143	0.99664
"A*B*S" INTERACTION	713.194	30	23.773		

MINUTE VENTILATION
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	177.352	2	88.676	2.28081	0.11965
"B" MAIN EFFECTS	43445.441	3	14481.812	372.48169	0.00000
"A*B" INTERACTION	499.033	6	83.172	2.13925	0.07783
"S" MAIN EFFECTS	5653.914	5	1130.782	29.08447	0.00000
"A*S" INTERACTION	893.589	10	89.358	2.29837	0.03823
"B*S" INTERACTION	3815.687	15	254.379	6.54280	0.00001
"A*B*S" INTERACTION	1166.377	30	38.879		

HEART RATE
THREE-WAY ANOVA
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	2482.583	2	1241.291	17.52434	0.00001
"B" MAIN EFFECTS	87371.125	3	29123.707	411.16357	0.00000
"A*B" INTERACTION	668.527	6	111.421	1.57303	0.18938
"S" MAIN EFFECTS	2542.791	5	508.558	7.17974	0.00016
"A*S" INTERACTION	1231.250	10	123.125	1.73826	0.11760
"B*S" INTERACTION	1787.486	15	119.165	1.68236	0.10982
"A*B*S" INTERACTION	2124.972	30	70.832		

APPENDIX D

MODIFIED STATISTIC CALCULATION FOR REPEATED MEASURES ON THE SAME SUBJECT

GLUCOSE
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	35.027	1	17.513	0.07880	n.s.
"A*S" INTERACTION	2222.472	5	222.247		
"B" MAIN EFFECTS	280.777	1	93.592	1.16612	n.s.
"B*S" INTERACTION	1203.888	5	80.259		
"A*B" INTERACTION	432.305	1	72.050	0.78786	n.s.
"A*B*S" INTERACTION	2743.527	5	91.450		

TOTAL FATTY ACID
THREE-WAY ANOVA
WITH REPEATED MESAURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	7.579	1	3.789	2.42957	n.s.
"A*S" INTERACTION	15.597	5	1.560		
"B" MAIN EFFECTS	2.029	1	0.676	3.19231	n.s.
"B*S" INTERACTION	3.178	5	0.212		
"A*B" INTERACTION	0.481	1	0.080	0.89415	n.s.
"A*B*S" INTERACTION	2.689	5	0.090		

SATURATED TOTAL FATTY ACID
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	61.841	1	30.921	3.78230	n.s.
"A*S" INTERACTION	81.751	5	8.175		
"B" MAIN EFFECTS	1.766	1	0.589	0.29910	n.s.
"B*S" INTERACTION	29.521	5	1.968		
"A*B" INTERACTION	2.871	1	0.478	0.35044	n.s.
"A*B*S" INTERACTION	40.964	5	1.365		

UNSATURATED TOTAL FATTY ACID
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	61.361	1	30.680	3.75437	n.s.
"A*S" INTERACTION	81.719	5	8.172		
"B" MAIN EFFECTS	1.889	1	0.630	0.31975	n.s.
"B*S" INTERACTION	29.546	5	1.970		
"A*B" INTERACTION	2.805	1	0.467	0.34376	n.s.
"A*B*S" INTERACTION	40.795	5	1.360		

LACTIC ACID
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	301.465	1	150.732	1.52070	n.s.
"A*S" INTERACTION	991.200	5	99.120		
"B" MAIN EFFECTS	28670.707	1	9556.902	28.73946	0.01
"B*S" INTERACTION	4988.039	5	332.535		
"A*B" INTERACTION	765.395	1	127.565	2.01515	n.s.
"A*B*S" INTERACTION	1899.101	5	63.303		

OXYGEN CONSUMPTION
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	1.024	1	0.512	3.76131	n.s.
"A*S" INTERACTION	1.361	5	0.136		
"B" MAIN EFFECTS	40.199	1	13.399	192.63206	0.01
"B*S" INTERACTION	1.043	5	0.695		
"A*B" INTERACTION	0.441	1	0.736	0.53627	n.s.
"A*B*S" INTERACTION	4.117	5	0.137		

OXYGEN CONSUMPTION PER KILOGRAM
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	201.450	1	100.725	4.11926	0.1
"A*S" INTERACTION	244.522	5	24.452		
"B" MAIN EFFECTS	7093.589	1	2364.529	395.58305	0.01
"B*S" INTERACTION	89.659	5	5.977		
"A*B" INTERACTION	83.823	1	13.970	0.58767	n.s.
"A*B*S" INTERACTION	713.194	5	23.773		

MINUTE VENTILATION
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	177.352	1	88.676	0.9923	n.s.
"A*S" INTERACTION	893.589	5	89.358		
"B" MAIN EFFECTS	43445.441	1	14481.812	56.9300	0.01
"B*S" INTERACTION	3815.687	5	254.379		
*A*B" INTERACTION	499.033	1	83.172	2.1392	n.s.
"A*B*S" INTERACTION	1166.377	5	38.879		

HEART RATE
THREE-WAY ANOVA
WITH REPEATED MEASURES ON THE SAME SUBJECTS
SUMMARY OF ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SS	DF	MS	F	P
"A" MAIN EFFECTS	2482.583	1	1241.291	10.08155	0.05
"A*S" INTERACTION	1231.250	5	123.125		
"B" MAIN EFFECTS	87371.125	1	29123.707	244.39665	0.01
"B*S" INTERACTION	1787.486	5	119.165		
"A*B" INTERACTION	688.527	1	111.421	1.57303	n.s.
"A*B*S" INTERACTION	2124.972	5	70.832		

APPENDIX E

RAW SCORES FOR ALL SUBJECTS ON EVERY ITEM

PHYSICAL CHARACTERISTICS OF SUBJECTS

SUBJECTS	AGE YEARS	WEIGHT KG	$\dot{M}VO_2$ L/MIN	$\dot{M}VO_2$/kg L/MIN/KG	MAX. $\dot{V}e$ L/MIN	MAX. H.R. BEATS/MIN
A.T.	25	76.02	2.23	29.3	109.75	225
A.L.	25	63.86	3.14	49.1	108.96	195
G.T.	34	70.34	2.92	41.4	93.13	180
J.J.	24	77.50	3.43	44.2	148.97	204
R.F.	27	79.09	3.24	41.0	123.16	180
S.G.	25	80.34	2.94	36.6	94.87	184
MEANS	26.7	74.53	2.98	40.27	113.14	194.7
S.D.	3.40	5.73	0.38	6.19	18.92	16.08

PLASMA GLUCOSE CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	87	65	91	88	67	86	86	62	86	64	72	77
A.L.	83	85	73	78	85	80	78	78	78	71	87	106
G.T.	101	91	94	100	96	84	100	84	82	93	84	84
J.J.	80	89	78	80	92	75	78	88	73	84	104	82
R.F.	89	80	82	91	80	86	83	78	75	65	89	45
S.G.	82	100	80	82	81	80	80	71	84	82	62	108
MEANS	87.0	85.0	83.0	86.5	83.5	81.8	84.2	76.8	79.7	76.5	83.0	83.7
S.D.	6.95	10.82	7.30	7.52	9.32	3.93	7.63	8.49	4.71	10.63	13.27	20.95

N.B. All measures in mg/100 ml

PLASMA TOTAL FATTY ACID CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	2.47	2.89	3.44	2.62	2.88	3.43	2.73	2.92	3.21	2.63	2.79	3.47
A.L.	3.18	3.03	4.27	3.41	3.86	4.02	3.76	3.60	4.41	3.99	3.46	4.25
G.T.	3.31	3.50	4.07	3.22	3.30	4.54	3.12	3.77	3.91	3.36	3.64	4.18
J.J.	3.31	2.25	2.55	3.69	2.26	2.82	3.62	2.64	3.16	3.74	3.06	3.54
R.F.	2.78	1.95	2.25	2.44	2.28	2.45	2.44	2.28	2.37	2.38	2.53	2.55
S.G.	4.33	5.48	6.69	4.64	6.14	6.61	4.86	7.74	8.28	4.72	6.28	8.36
MEANS	3.23	3.18	3.88	3.34	3.45	3.98	3.42	3.83	4.22	3.47	3.63	4.39
S.D.	0.63	1.26	1.59	0.80	1.45	1.50	0.87	2.00	2.11	0.87	1.36	2.04

N.B. All measures in mg/ml plasma

PLASMA PALMITIC ACID CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	0.58	0.75	0.86	0.66	0.74	0.86	0.67	0.70	0.81	0.62	0.71	0.95
A.L.	0.84	0.85	1.17	0.90	1.06	1.02	0.98	1.03	1.22	0.99	0.97	1.17
G.T.	0.79	0.90	0.98	0.78	0.80	1.11	0.77	0.93	0.97	0.79	0.91	1.08
J.J.	0.80	0.63	0.76	0.92	0.69	0.93	0.92	0.76	0.96	0.92	0.92	1.03
R.F.	0.63	0.50	0.67	0.58	0.54	0.64	0.58	0.56	0.65	0.53	0.62	0.67
S.G.	1.14	1.24	1.66	1.18	1.53	1.68	1.26	2.07	2.05	1.21	1.44	1.95
MEANS	0.80	0.81	1.02	0.84	0.89	1.04	0.86	1.01	1.11	0.84	0.93	1.14
S.D.	0.18	0.23	0.33	0.20	0.32	0.32	0.22	0.50	0.45	0.23	0.26	0.39

N.B. All measures in mg/ml

PLASMA STEARIC ACID CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	0.25	0.23	0.29	0.22	0.26	0.30	0.24	0.21	0.28	0.24	0.26	0.27
A.L.	0.31	0.32	0.45	0.36	0.42	0.42	0.40	0.38	0.44	0.42	0.38	0.43
G.T.	0.35	0.45	0.45	0.32	0.39	0.48	0.30	0.46	0.44	0.41	0.42	0.42
J.J.	0.31	0.22	0.26	0.35	0.23	0.28	0.34	0.27	0.35	0.37	0.31	0.39
R.F.	0.33	0.21	0.24	0.26	0.26	0.26	0.26	0.26	0.23	0.26	0.28	0.26
S.G.	0.32	0.44	0.57	0.37	0.58	0.49	0.35	0.84	0.73	0.36	0.49	0.74
MEANS	0.31	0.31	0.38	0.31	0.36	0.37	0.32	0.40	0.41	0.34	0.56	0.42
S.D.	0.03	0.10	0.12	0.06	0.12	0.10	0.06	0.21	0.16	0.07	0.08	0.16

N.B. All measures in mg/ml

PLASMA LINOLEIC ACID CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	0.77	0.84	1.06	0.85	0.81	1.03	0.89	0.90	0.97	0.86	0.82	0.99
A.L.	0.97	0.95	1.20	1.04	1.21	1.22	1.14	1.08	1.31	1.28	1.04	1.21
G.T.	1.02	1.01	1.15	0.99	0.98	1.21	0.96	1.08	1.02	1.02	1.04	1.15
J.J.	0.95	0.65	0.69	1.01	0.65	0.72	1.03	0.79	0.83	1.03	0.84	0.95
R.F.	0.87	0.73	0.60	0.78	0.85	0.72	0.75	0.78	0.67	0.73	0.91	0.73
S.G.	1.05	1.45	1.70	1.16	1.59	1.68	1.20	1.98	2.07	1.19	1.68	2.20
MEANS	0.94	0.94	1.07	0.97	1.02	1.10	1.00	1.10	1.15	1.02	1.06	1.21
S.D.	0.09	0.26	0.36	0.13	0.31	0.33	0.15	0.41	0.46	0.19	0.29	0.47

N.B. All measures in mg/ml

PLASMA OLEIC ACID CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	0.74	0.94	1.09	0.79	0.92	1.10	0.82	1.03	1.01	0.77	0.87	1.04
A.L.	0.91	0.80	1.17	0.97	1.03	1.16	1.06	0.97	1.29	1.11	0.93	1.25
G.T.	1.02	0.98	1.28	1.01	1.01	1.56	0.98	1.13	1.30	1.03	1.11	1.37
J.J.	1.13	0.60	0.71	1.23	0.59	0.77	1.18	0.69	0.84	1.26	0.79	0.98
R.F.	0.85	0.44	0.63	0.75	0.52	0.70	0.78	0.54	0.73	0.79	0.62	0.79
S.G.	1.62	2.07	2.44	1.66	2.11	2.52	1.83	2.53	3.01	1.74	2.45	3.08
MEANS	1.05	0.97	1.22	1.07	1.03	1.30	1.11	1.15	1.36	1.12	1.13	1.42
S.D.	0.29	0.53	0.59	0.31	0.52	0.61	0.35	0.65	0.77	0.33	0.61	0.77

N.B. All measures in mg/ml

PLASMA PALMITOLEIC ACID CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	0.13	0.13	0.14	0.10	0.15	0.14	0.11	0.08	0.14	0.14	0.13	0.22
A.L.	0.15	0.11	0.28	0.14	0.14	0.20	0.18	0.14	0.15	0.19	0.14	0.19
G.T.	0.13	0.16	0.21	0.12	0.12	0.18	0.11	0.17	0.18	0.11	0.16	0.16
J.J.	0.12	0.15	0.13	0.18	0.10	0.12	0.15	0.13	0.18	0.16	0.20	0.19
R.F.	0.10	0.07	0.11	0.07	0.11	0.13	0.07	0.14	0.09	0.07	0.10	0.10
S.G.	0.20	0.28	0.32	0.27	0.33	0.24	0.22	0.32	0.42	0.22	0.22	0.39
MEANS	0.14	0.15	0.20	0.15	0.16	0.17	0.14	0.16	0.19	0.15	0.16	0.21
S.D.	0.03	0.07	0.08	0.07	0.08	0.04	0.05	0.08	0.11	0.05	0.04	0.09

N.B. All measures in mg/ml

PLASMA LACTIC ACID CONCENTRATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	9.5	10.0	6.0	15.5	12.0	9.5	19.0	18.0	27.0	71.0	28.0	40.0
A.L.	10.0	3.0	8.5	15.5	18.5	10.5	39.0	45.0	50.0	61.0	55.0	89.0
G.T.	8.5	14.0	11.0	23.0	17.0	24.0	46.0	29.0	45.0	81.0	42.0	63.0
J.J.	6.0	6.0	8.5	17.0	15.0	14.0	43.0	45.0	50.0	81.0	102.0	95.0
R.F.	8.0	11.0	5.0	15.5	14.0	7.5	41.0	44.0	37.0	72.0	52.0	50.0
S.G.	7.0	8.0	5.0	15.0	11.5	11.0	18.0	21.0	27.0	22.0	16.0	44.0
MEANS	8.2	8.7	7.3	16.9	14.7	12.8	34.3	33.7	39.3	64.7	49.2	63.5
S.D.	1.37	3.54	2.19	2.79	2.51	5.39	11.40	11.48	9.74	20.25	27.18	21.40

N.B. All measures in mg/100 ml

OXYGEN CONSUMPTION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	0.46	0.17	0.51	2.44	2.27	1.08	2.56	1.07	2.57	2.34	1.44	2.53
A.L.	0.35	0.31	0.39	1.62	1.64	1.61	2.04	1.36	1.66	1.68	1.42	2.01
G.T.	0.34	0.21	0.43	1.92	1.33	1.68	2.26	1.80	1.72	1.90	2.37	1.86
J.J.	0.25	0.17	0.18	1.95	2.13	1.62	2.62	2.25	2.16	3.21	2.19	1.89
R.F.	0.56	0.28	0.22	2.20	1.63	2.27	2.71	2.86	1.90	2.84	2.52	1.87
S.G.	0.13	0.33	0.18	1.91	2.05	1.44	1.98	2.11	1.85	1.92	2.11	2.19
MEANS	0.35	0.25	0.32	2.01	1.84	1.62	2.36	1.91	1.98	2.32	2.01	2.06
S.D.	0.14	0.07	0.13	0.26	0.33	0.35	0.29	0.59	0.31	0.55	0.43	0.24

N.B. All measures in L/min

OXYGEN CONSUMPTION PER KILOGRAM

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	5.87	2.19	6.47	31.53	29.54	13.52	32.88	13.50	32.34	30.09	18.25	31.86
A.L.	5.50	4.81	6.09	25.15	25.31	25.21	31.73	20.77	25.76	25.96	21.64	31.39
G.T.	4.80	2.90	6.15	27.00	18.49	23.61	32.26	25.22	24.02	26.69	33.28	26.06
J.J.	3.09	2.06	2.22	24.25	26.49	19.87	32.76	27.87	26.69	40.34	26.99	23.34
R.F.	7.04	3.47	2.61	27.31	20.44	27.75	33.59	36.05	22.79	35.43	31.68	22.55
S.G.	1.56	4.06	2.24	23.68	25.31	17.66	24.40	26.10	22.92	23.74	26.14	27.25
MEANS	4.65	3.23	4.27	26.73	24.47	21.52	31.58	25.23	26.13	30.65	26.62	27.38
S.D.	1.85	0.98	1.97	2.55	3.63	4.78	3.14	6.82	3.23	5.79	5.16	3.57

N.B. All measures in L/min/kg

MINUTE VENTILATION

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	23.54	27.51	20.96	65.21	57.42	58.83	80.00	71.00	79.24	75.94	74.58	92.10
A.L.	17.16	19.71	17.37	49.79	50.02	45.68	62.48	57.09	53.97	57.21	54.87	95.86
G.T.	18.97	12.40	18.19	55.94	40.62	44.95	66.37	55.03	58.25	91.23	58.40	73.07
J.J.	20.55	12.98	10.90	61.29	58.79	51.98	81.85	80.59	81.59	115.55	117.50	117.57
R.F.	25.48	29.32	20.18	62.08	55.39	55.06	86.62	92.46	77.47	108.25	100.90	91.38
S.G.	10.39	11.62	12.99	49.07	53.30	52.38	53.40	57.90	59.56	62.04	59.18	72.72
MEANS	19.35	18.92	16.77	37.88	36.65	51.48	71.79	69.01	68.35	85.15	77.59	90.45
S.D.	4.86	7.23	3.66	6.16	6.05	4.90	11.85	13.84	11.28	21.85	23.71	15.19

N.B. All measures in L/min

HEART RATE

SUBJECTS	REST			2 MIN			7 MIN			20 MIN		
	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM	4°C COLD	21°C STD.	40°C WARM
A.T.	88	78	100	145	150	150	164	167	164	167	170	195
A.L.	96	79	89	145	141	155	164	145	164	164	167	204
G.T.	65	100	118	145	148	155	161	161	164	167	170	184
J.J.	86	63	101	161	167	173	187	184	187	195	195	204
R.F.	91	70	85	148	136	150	161	167	158	173	170	167
S.G.	81	90	105	145	153	161	155	155	176	161	170	195
MEANS	84.5	80	99.7	148.2	149.2	157.3	165.3	163.2	168.8	171.2	173.7	191.5
S.D.	9.85	12.21	10.77	5.84	9.79	7.93	10.14	12.01	9.34	11.26	9.60	12.87

N.B. All measures in beats/min